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STRATIGRAPHY OF THE HAMILTON GROUP OF EASTERN NEW YORK.

G. ARTHUR COOPER.

PART II.

Moscow Formation.

Happily the Portland Point, basal member of the Moscow formation, was traced into Susquehanna Valley, and from there eastward through Schoharie Valley into the red beds at Potter Hollow not far northwest of the village of Durham, Greene County. At Milford, eight miles south of Cooperstown, the Portland Point is splendidly exposed in the bed and banks of Hinman Hollow Brook, where it is a hard, coarse, bluish, massive, calcareous sandstone. In the basal bed at this exposure *Vitulina pustulosa* and *Centronella impressa* are fairly common, the latter ranging through the whole six feet of the member. Somewhat diminished in thickness the Portland Point is present in Bear Gulch just north of Summit and was traced three miles eastward to a small tributary of Panther Creek on the property of Tobias Wayman. Here it measured four feet in thickness, the lower one and one-half feet being mostly thin, calcareous sandstone lenses in arenaceous shale and containing *Vitulina pustulosa* in some abundance. From here the bed was traced into Schoharie Valley where it is exposed along the old road up Mill Creek, one and one-half miles west of North Blenheim. This locality exposes the "pebble bed" of Prosser,[12] which is the Portland Point. Thence it was followed to a gully one mile southwest of North Blenheim, on the west side of the valley, and to a gully three-fourths of a mile southeast of the same village on the east side of the valley. At these localities the Portland Point consists of coarse sandstone and quartz pebbles, some of them two inches in diameter, and contains fossils in great abundance. *Centronella impressa* was discovered but *Vitulina* could not be

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[12] N. Y. St. Geol. Ann. Rep. 15, pp. 202, 203, 1897.

found. Despite the absence of *Vitulina,* all of the
corroborated the identification of this bed as Port
Among other species found were: *Eunella linckl*
domella vanuxemi, Cypricardella bellistriata,
decussata, all rare or unknown elsewhere in the vall

On a small tributary of Catskill Creek one an
miles southwest of Potter Hollow, Durham Quad
exposure of some ten and one-half feet of coars
at the base of which is about one foot of conglo
this conglomerate *Centronella* occurs together
fossils which are of little value for correlation.
sandstones are soft bluish shales containing large
pelecypods, among them *Cypricardella bellistria*
elsewhere in the base of the Windom only. The wr
that the sandstones with *Centronella* are to be cor
the Portland Point. The basis for this correlatio

1. These sandstones are on the strike and dip of th
Portland Point which lies farther to the northwest.
2. In Schoharie Valley *Cypricardella bellistriata* wa
at two horizons only, in and immediately above the Po
3. The Centronellas are of the large type characte
Portland Point.

Against these arguments may be raised the poi
tronella is a facies fossil occurring elsewhere in
the coarse sandstones, and, therefore, of little valu
tion. However, all of the centronellas observed b
in beds outside of the Portland Point average s
C. impressa and appear to be a new species. If th
correlation of the Portland Point at Potter Hollow
it allows the redating of a good part of the red
Catskill Front.

The Portland Point is a very valuable datum p
continuous from Cayuga Lake to Schoharie Valley
Hollow. Why is this bed so widespread and why
show the same type of facies relationships as the
and below it? A tentative suggestion to answer
tions follows. It is possible that this member
during a time of little or no deposition, a time
of the sea-bottom, when fine material was swept aw
only the coarser grains and testaceous animal debri
Such an explanation may be the reason for the lar
of crinoidal limestone and shell breccia at the
Portland Point. These features suggest an asso

fifty feet below the original surface of the hill. It was almost in the center of the forty-foot pegmatite dike which at this point is nearly vertical. The following quotations from letters of Mr. Burbank describe what had been developed when our work began.

December 28, 1932. "In 1929 I stumbled upon the place while prospecting in some old quarries (the Fisher Quarry). The pocket had been hardly opened at the time the quarry was abandoned The opening would not permit one to put his hand into it, being closed by a large book of greenish muscovite bordered by lilac lepidolite. On removal of this a cavity of about one cubic foot was exposed, the roof being covered with quartz crystals. On the face of one of these was a yellowish, fractured topaz* crystal of small size. The back wall of the pocket was composed of a spongy, porous, very hard material of greenish color which I assumed to be a completely disintegrated beryl. Probably one hundred pounds of this material has been taken from the pocket since I opened it and shows some clear gemmy material. There is also abundant cleavelandite, lepidolite and blue tourmaline. The bottom of the pocket was of a clay material intermingled with small quartz crystals, some shells of lepidolite, and, deeper down, topaz of various colors, some crystals loose, some embedded in lepidolite. Tourmaline in small blue crystals, cassiterite and columbite were also found."

In May, 1933, Mr. Burbank wrote again after another visit to the quarry in which he found herderite in great abundance, mistaken at first for topaz which it much resembles in form.

"Yesterday Mr. Starbird of the Maine Mineralogical Society visited with me and we went to the locality of the topaz. We collected the finest specimens from there that have been found in all my visits. The finest pair of almost perfect crystals, each two inches long, is shown in the sketch." (This was a superb group of herderites.) ". . . . . . . the pocket occurs on the floor of the quarry and from that and other indications we both believe it is just the top showing of a much larger pocket or group of pockets. I probed the pocket I mentioned before and estimate it to be four feet deep now. It is filled with water but from the roof we took many good specimens."

As it proved these pockets were the upper end of an upward, pipe-like extension of the main cavity beneath, which lay some six feet below the point of discovery.

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*Found later to be a herderite.

A TOPAZ DEPOSIT IN TOPSHAM, MAINE.

CHARLES PALACHE.

Topaz is one of the least common among the many pegmatite minerals found in New England. The only description of any abundant occurrence of it records the discovery of the pocket in Stoneham, Maine, which was described by George F. Kunz.[1]

The present paper describes an occurrence of topaz comparable in importance and similar in origin to that at Stoneham. The nature of the material and the circumstances attending its excavation seem to justify the following rather detailed account.

In 1929, Mr. B. B. Burbank, a chemist and mineral collector of Brunswick, Me., found in the old feldspar working in Topsham known as the Fisher Quarry[2] a group of minerals not hitherto met with so far south in Maine. Cleavelandite and lepidolite were the most striking minerals and, in small vugs in these, blue topaz and beryl in deeply etched fragments were present. Mr. Burbank was away from Brunswick for some time after this discovery and it was not until the winter of 1932 that he drew my attention to the occurrence, desiring accurate identification of some of his minerals. Our correspondence lasted through the spring of 1933, and the interest of what he sent me and of what he was able to tell me about the deposit was such that I visited Brunswick in June to see Mr. Burbank's collection and was taken to the locality. To both of us it seemed evident that the deposit extended downward and promised to reward the labor of excavation. I at once proceeded to obtain permission from the owner of the lease, Mr. W. D. Willes of Topsham, to develop the deposit for the benefit of the Harvard Mineralogical Museum. Mr. Willes readily consented and early in July Mr. F. A. Gonyer, one of the staff of the Museum, began the work with the effective aid of Mr. Burbank.

The point where the minerals occurred was on an old floor of the quarry at the base of a high bank of low-grade pegmatite which had been left standing during the operation of the quarry. According to Mr. Willes this floor was about on the sea-bottom, allowing the retention in situ of shell and crinoid remains only. If formed in this manner, the Portland Point may be looked upon as representing a minor break.

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[1] Topaz and Associated Minerals at Stoneham, Me., this Journal, 27, 212, 1884.

[2] Bastin, E. S. Geology of the Pegmatites of Maine, Bull. 445, U. S. G. S., 112, 1911.

With the correlation of the Portland Point established it was an easy matter to follow the Windom member, which is the interval from the Portland Point to the top of the Hamilton. In Susquehanna Valley the Windom member is essentially like that of Unadilla Valley, but the faunal zones which are so clear in Chenango Valley become less easy to trace in Unadilla Valley and are nearly unrecognizable south of Milford in Susquehanna Valley. Traced eastward the Windom member becomes sandier and its fossils less abundant. In Summit Hill, one mile north of Summit, along Bear Gulch Pond and its outlet, the entire Windom is exposed. In this section there is a preponderance of argillaceous sandstone, much of it cross-bedded. Plant fragments are abundant. East of Summit the bulk of the Windom passes laterally into continental beds, the layers with the famous tree-stumps being near the middle of the member. Of interest, too, is the presence of the fresh-water clam *Amnigenia* (*Archanodon*) some sixty feet above the Portland Point.

In Otego and Susquehanna Valleys the top of the Windom is marked by the *Hypothyridina-Leiorhynchus mesacostale* zone of the Tully formation. The *Leiorhynchus* zone can be traced definitely as far east as Schenevus, and is recognizable, but not clearly so, to Summit Hill. East of here the top of the Windom could not be traced easily but is thought to be in the red beds on the Manorkill at West Conesville.

The *Vitulina* zone of the upper Windom can be traced continuously from Otisco Lake to Summit Hill, thus forming an exceedingly valuable datum plane for tracing the top of the Hamilton. Since *Hypothyridina* and *Leiorhynchus mesacostale* are difficult to find east of Susquehanna Valley the *Vitulina* zone was relied on for the detection of the top of the Hamilton. In Otego Valley the *Hypothyridina-Leiorhynchus* zone occurs sixty feet above the *Vitulina* and east of here as far as Schenevus *Leiorhynchus* alone occurs just below a storm-roller bed about sixty feet above *Vitulina*. At Summit Hill a storm-roller bed was found thirty-five feet above the *Vitulina* zone but no fossils were collected from it. *Leiorhynchus mesacostale* was seen fifty to sixty feet above *Vitulina* at the same place. East of Summit the writer failed to find *Vitulina* although an exhaustive search was made for it. The determination of the top of the Hamilton, therefore, could not be made precisely. It has been drawn above a zone containing peculiar terebratuloids in abundance which is on the strike and dip of the *Vitulina* zone projected from Summit into Schoharie Valley.

The estimated thicknesses of the Windom member are: Susquehanna Valley, 409 feet; Bear Gulch to Summit Hill, 440 feet; and Schoharie Valley, 519 feet. East of Schoharie Valley the Windom has passed into red-beds and the thickness is unknown.

RED AND GREEN BEDS.

The subject of red and green beds is always one of interest and those of Schoharie Valley and eastward are no exception. In eastern New York the lowest red sediments have always been taken as the beginning of Oneonta sedimentation. Most geologists have been aware that these red beds increase in age as they are followed to the east, but few would be prepared to admit that some of them are of Hamilton age and actually rather early in the Hamilton. The lowest red beds seen in Schoharie Valley are those of the upper part of the Panther Mountain division exposed near the summit of Moheganter Mountain. The next red beds observed in the Hamilton are those along the road to Grand Gorge about three and one-half miles south of North Blenheim, which are in the position of the *Vitulina* zone and the Hamilton interval between this zone and the true top of the Hamilton. The red beds of Manorkill gorge are in the top of the Windom member.

On Berne Quadrangle the red beds appear still lower in the Hamilton than in the Moheganter Mountain section. In the ravine at Rensselaerville the fossiliferous Hamilton is succeeded by some forty feet of green beds. It is then followed by a mottled zone, and then by red beds. These red sediments are stratigraphically in the lower part of the Skaneateles formation. From this uppermost fossiliferous bed at Rensselaerville to the Portland Point at Potter Hollow there is a considerable thickness of red and green beds. On the road from Potter Hollow to Manorkill over Van Steenburg Mountain are numerous outcrops of red and green beds, all of which overlie the Portland Point. A little west of Catskill village the fossiliferous Hamilton (not the same as fossiliferous Hamilton on the Berne Sheet) is known as the Mount Marion beds and is about eight hundred feet thick. This is succeeded by the Ashokan beds, mostly flaggy sandstones for about three hundred feet. The Ashokan division is followed by a great thickness of red beds, and intercalated greenish, cross-bedded sandstones, the Kiskatom beds of Chadwick, beautifully displayed along the highway up the Kaaterskill to Haines Fall and Tannersville. Much of this section undoubtedly belongs to the Hamilton and Gilboa (see page 6) divisions. At the present writing it is impossible to give the equivalents of the Mount Marion and Ashokan beds in the section southwest of Albany, but from thickness alone, it would appear that these two divisions do not represent more than the Marcellus.

Red beds were not seen west of Schoharie Valley, but along the highway between Richmondville and Summit about one and one-half miles south of Richmondville the first beds of green, crumbly, sandy shale appear in the upper part of the Skaneateles. In Schoharie Valley beds of this kind occur at many horizons in the Ludlowville and Skaneateles. These are well exposed along the Grand Gorge highway (30) at North Blenheim and for about three-fourths mile to the south.

BEDS SUPERJACENT TO THE HAMILTON.

In eastern New York the overlying beds are so closely linked to the Hamilton both faunally and lithologically that a brief discussion of their relationships is not out of place here.

Laurens member.—This name is suggested for the interval of rock located between New London and Schenevus which carries a *Hypothyridina* and a modified Ithaca fauna. The name is needed because the *Hypothyridina* zone in eastern New York is a different facies from that of the Tully and actually represents the basal portion of the Tully only according to present knowledge of the relationships. In Cazenovia and Morrisville Quadrangles *Hypothyridina* is restricted to the basal bed of the Tully limestone, a bed averaging a little more than one foot in thickness and composed of hard, sandy limestone. Above this zone in Morrisville Quadrangle are eighteen feet of argillaceous limestone in which *Hypothyridina* has never been found. At West Brook on the east side of Chenango Valley about three miles south of Sherburne, *Hypothyridina* is restricted to a ferruginous oölite four inches thick, which is followed by sandstones carrying a modified Hamilton fauna. The Tully interval has never been identified in Unadilla Valley except for the discovery by the writer of a layer of calcareous lenses containing *Hypothyridina.* So far as known the whole Sherburne, including the part of it assignable to the Tully, is quite unfossiliferous.

In eastern New York, from New Lisbon eastward, *Hypothyridina* is abundant in the shaly sandstones above the Hamilton. The vertical range of *Hypothyridina* in Butternut Valley, next valley east of Unadilla valley, is wholly unknown. Prosser[13] reports the presence of *Hypothyridina* above the Hamilton but does not give its vertical range. In Otego Valley, between Butternut and Susquehanna Valleys, *Hypothyridina* ranges vertically for seventy feet and is associated with a few other fossils, notably *Leiorhynchus mesacostale* which occurs in great numbers in the lowest bed. In Susquehanna Valley *Hypothyridina* was not found in the basal bed with *Leiorhynchus* but was found in some abundance fifty-two feet above the top of the Hamilton. At about the same level, *Hypothyridina* was found as far east as Schenevus, but east of here it was lost. It appears from present knowledge that the eighty-eight[14] feet of Laurens member in Otego Valley is the equivalent of the four-inch thick oölite with *Hypothyridina* in Chenango Valley. A possible explanation of this remarkable relationship is that the region now the site of Unadilla Valley and adjacent territory for short distances to the east and west was at wave-base during the time of deposition of the Laurens.

If the reader will not admit the correlation of the four-inch oölite of West Brook with the eighty-eight feet of Laurens member in Otego Valley an alternative may be suggested, as follows: The Laurens may be the shaly sandstone facies of the Tully-Geneseo formations. According to this scheme the Geneseo replaces the Tully to the west, the replacement being complete at Canandaigua Lake. The Laurens, on the other hand, replaces the Tully and Geneseo eastward, the passage beds lying between Chenango and Butternut Valleys. The relationship of the facies would be similar to that shown below in the Hamilton by westward replacement of the shaly sandstone Hamilton by the black shale or Marcellus facies.

Equally as remarkable as the vertical range of *Hypothyridina* in Susquehanna Valley is the fauna associated with this familiar Tully fossil. On both sides of the Portlandville

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[13] N. Y. St. Geol. Ann. Rep. 15, p. 183, 1897.

[14] Fossils occur for eighteen feet above the highest *Hypothyridina* in Otego Valley.

Reservoir, a little south of Milford Center, Susquehanna Valley and in a ravine a short distance south of Chaseville *Paracyclas lirata* and *Actinopteria boydi* were found associated with the *Hypothyridina*. In the Hamilton of Chenango Valley *Paracyclas lirata*, according to the writer's knowledge, is restricted to the Marcellus and Skaneateles divisions, reappearing in the base of the Ithaca some three hundred feet above the Hamilton. In eastern New York this fossil occupies the beds from the top of the Hamilton into the Ithaca.

Sherburne formation.—At West Brook on the east side of Chenango Valley the Geneseo is doubtfully represented by some black shales and dark sandy shales of the Sherburne. The Sherburne can be traced into the region around Schenevus, after which it is lost. There is absolutely no Sherburne in Schoharie Valley in the vicinity of North Blenheim, as reported by Prosser,[15] and there are no beds referable to this formation in the Berne Quadrangle although this formation, much diminished in thickness, has been reported in the ravine at Rensselaerville. Between Sherburne village and Schenevus the Sherburne consists of dark gray, sandy shales and flaggy sandstones, without fossils, so far as known. But in the vicinity of Schenevus fossils occur, which are those of the Ithaca facies, *Sp. mesastrialis* appearing frequently, together with *Actinopteria boydi* and other pelecypods. Still farther eastward this fauna has not only occupied the pre-Ithaca Sherburne but has also invaded the Tully equivalent, *Sp. mesastrialis* being common in the sandstones about seventy feet above the *Vitulina* zone in Summit Hill. In Unadilla Valley the thickness of the Sherburne has been estimated to be 253 feet. In Susquehanna Valley it is 213 feet thick.

Gilboa beds.—In Schoharie Valley in the vicinity of Gilboa and southward along the shores of Gilboa Reservoir *Sp. mesastrialis* and other Ithaca fossils are common in the sandstones. This division, about 250 feet thick, is the equivalent of the Tully (Laurens) and Sherburne sandstone, or in other words, is the Ithaca facies of the Sherburne, Geneseo, and Tully. A nearly complete section of these rocks can be studied in the west face of Reed Hill. Other exposures are in the huge quarry in Stevens Mountain and along the road leading from the Intake Building at the base of Pine Mountain to Hardenburgh Falls on the Bear Kill. The exposures in Reed Hill have been selected for the type section.

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[15] N. Y. St. Geol. Ann. Rep. 15, pp. 197, 313, 1897.

Ithaca formation.—Along the Grand Gorge road to Schoharie (Highway 30) about two miles northeast of Grand Gorge, at an elevation of 1,406 feet above sea-level, there are lenses of shell-breccia composed chiefly of *Sp. mesastrialis*, *Tropidoleptus* and a few other fossils. These calcareous lenses apparently are at the base of the Ithaca although the fauna can scarcely be separated from that of the Gilboa beds below. West of Schoharie Valley similar beds occur at the undoubted base of the Ithaca and the beds on the Grand Gorge-Schoharie road are on the dip and strike of the base of the Ithaca as determined elsewhere. Similar lenses to those described above can be found at many localities in the vicinity of Gilboa and for some distance to the north, all lying near the same level. Good exposures can be studied at Hardenburgh Falls on Bear Kill, in a ravine just north of Ruth, and in an outcrop one mile due west of Conesville. Above the *Sp. mesastrialis* beds on the Grand Gorge road (Highway 30) and elsewhere is a succession of red shales, sandstones, greenish-gray sandstones and green shale and sandstone which are the equivalent of the lower Ithaca (Otselic) and thus not to be correlated with the true Oneonta red beds, but are below them, though here of similar facies.

Prosser[16] erred in his determination of the Ithaca in Schoharie Valley. The beds about North Blenheim, which he assigned to this formation and to the Sherburne, belong in the upper part of the Skaneateles, the Ludlowville and the Moscow. This explains the statement that appears in Prosser's writings and has been quoted in other books, that the Sherburne east of its type locality becomes fossiliferous and the fossils are those of the Hamilton.[17] It also explains the great abundance of Hamilton fossils placed in faunas assigned to the "Ithaca" in eastern New York, fossils unknown in the Ithaca of the type region and Chenango Valley. The present work appears to invalidate the well-known Sherburne bar theory of Grabau.

The range of *Spirifer mesastrialis* in Schoharie Valley is interesting and important. It is found all through the Gilboa member and consequently is Tully, Geneseo and Sherburne in age as well as Ithaca. It is not, however, confined to the Gilboa beds but ranges down into rocks that are clearly in the upper Hamilton. This species has been found along the

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[16] Prosser, op. cit., p. 313, and map.

[17] Grabau, A. W., Bull. Geol. Soc. Amer., 30, p. 426, 1919.

Grand Gorge-Schoharie road four and one-half to five miles south of North Blenheim in beds underlying the "Terebratuloid" zone, which are known to be at the level of the *Vitulina* zone. It has been doubtfully identified from a hard sandstone bed overlying the upper tree horizon on the Manorkill. Thus, it is certain that this element of the Ithaca fauna has invaded the upper Hamilton.

The Ithaca fauna is a recurrent Skaneateles fauna and represents the *Tropidoleptus* or Hamilton facies which replaces the Portage *Leiorhynchus* or black shale (Marcellus) facies in an easterly direction. The facial conditions of the Hamilton are thus repeated in post-Hamilton time, but the faunas are essentially the same as those that lived in Hamilton time. It is thus not surprising to find spirifers almost indistinguishable from *Sp. mesastrialis* appearing in the Marcellus-Skaneateles rocks. And with these spirifers are other familiar Ithaca species: *Actinopteria boydi, Paracyclas lirata,* and *Palaeoneilo emarginata.* In like manner the black shale facies of the Marcellus-Skaneateles contain *Buchiola* and *Pterochaenia.*

REGIONAL STRATIGRAPHY.

The foregoing discussion has centered around the stratigraphic units small and large. There has been no attempt made to orient the reader as to the geographic distribution of the various Hamilton strata in this little known region. The following is a brief description of the geographical distribution of Hamilton beds in Susquehanna and Cherry Valleys, Bear Gulch between Summit and Richmondville, and the Schoharie Valley.

In Susquehanna Valley the Onondaga limestone is exposed at the north end of Otsego Lake in and about the villages of Springfield and Springfield Center. The southernmost exposure is about one-half mile south of the north end of the lake and the limestone must disappear by dip about one mile still farther south. The Chittenango, Otsego, and Solsville shales and sandstones are exposed on both sides of the lake as far south as Cooperstown, which is underlain by the Solsville. The Panther Mountain shales and sandstones are exposed in the hills on each side of the lake north of Cooperstown and on both sides of the valley south of Cooperstown to Milford, eight miles to the south. In Cherry Valley, which joins the Susquehanna at Milford, the Onondaga is exposed in the village of Cherry Valley and the Marcellus beds up to the Solsville are exposed in the hills to the north and south. The top of the Solsville is exposed in the little village of Pleasant Valley and descends beneath the valley floor about three miles south of Roseboom. The Panther Mountain division is then exposed in the ravines and hillsides south to Milford. In the lower part of the ravines about Milford the Portland Point is well exposed and descends beneath the valley floor a little more than a mile south of the village. The Moscow is exposed from this point almost to Milford Center about six miles south of Milford. The Laurens member of the Tully is exposed on both sides of the Portlandville Reservoir; the Sherburne occurs in the ravines about Colliers (Colliersville).

At Richmondville railroad station the top of the Solsville is exposed along the tracks and rises rapidly to the northeast. Along the Delaware and Hudson Railroad tracks opposite Warnerville the Solsville beds are well displayed. In the gorge and falls of Bear Gulch Creek in the village of Richmondville the top of the Solsville is again exposed. From Richmondville southward up the hill toward Fly Pond on the west side of Bear Gulch are good exposures of the lower part of the Panther Mountain beds which here roughly correspond to the Pecksport, Mottville and Skaneateles. Along the main road to Summit, on the east side of the Gulch, are outcrops of the upper Panther Mountain which correspond very closely to the Ludlowville. This same interval is exposed along the road, on the west side of the Gulch, which makes the steep descent from Bear Gulch Pond to Richmondville. The Portland Point is exposed in Bear Gulch at an elevation of 1,960 feet above sea-level. Excellent outcrops of the lower Moscow may be studied in Bear Gulch above the Portland Point and on the shores of Bear Gulch Pond. These Moscow (Windom) exposures extend to 2,340 feet above sea-level in Summit Hill, at which level the *Vitulina* zone appears. Above this zone are about forty-five feet of rock belonging to the Hamilton Group. At the top of Summit Hill is a huge flagstone quarry which represents a portion of the eastern equivalent of the Laurens at the base of the Gilboa. The latter is exposed southward from Summit to Jefferson where the base of the Ithaca is known to occur.

In Schoharie Valley the Onondaga limestone is exposed in Schoharie Creek about one mile northwest of Middleburg village. The Chittenango member and the beds containing the

Meristella-Coral zone are exposed in the headwaters of Stony Creek, one and one-half miles southeast of Schoharie village. The Otsego member of the Marcellus formation outcrops in the hills to the northeast and northwest of Middleburg. Excellent exposures are in "The Cliffs" just northeast of the village and the lower three hundred feet of Vromans Nose, one and one-half miles southwest of Middleburg. The top of the Otsego bed descends beneath the valley floor about three-fourths of a mile south of Fultonham. Then follows the Panther Mountain division to a point about one and one-half miles south of North Blenheim. The lower part of the Panther Mountain is exposed in the cliffs along the "Towpath," in Boucks Falls and the falls of the Keyser Kill, one mile east of Breakabeen. The middle and upper beds are to be seen about North Blenheim. The Panther Mountain division in Schoharie Valley includes the Marcellus beds from the Otsego to the Mottville, the Skaneateles and the Ludlowville. On the basis of faunas the Marcellus formation extends from the top of the Onondaga north of Middleburg to a point about one and one-half miles south of Breakabeen; the Skaneateles extends from here to a point probably less than one-half mile south of North Blenheim; the Ludlowville on the basis of faunas extends from about one-half mile south of North Blenheim to a point about one mile north of Gilboa.

The Portland Point and the Windom are exposed southward from Mill Creek to Manorkill. The Portland Point passes under the floor of the valley about one mile north of Gilboa. The supposed top of the Hamilton is exposed on the banks of the Manorkill at West Conesville and along the North Blenheim-Grand Gorge highway (30) three and one-half miles south of North Blenheim.

The Gilboa beds, representing the combined Laurens and Sherburne, are exposed in the hills to the north of Gilboa and along the shores of the reservoir south of the Gilboa dam. The Ithaca is exposed along the road to Grand Gorge from Gilboa, in Pine Mountain, and in Hardenburgh Falls near the mouth of the Bear Kill.

NOTE TO THE CORRELATION CHART (FIGURE 3).

The correlation chart has been prepared on such a small scale that it was impossible to record much detail. For example, it was not possible to illustrate the many thin green beds of the Panther Mountain or all of the subtle lithologic changes which can be distinguished in the field and which are useful to identify certain of the beds. In this eastern New York Hamilton there are few rocks that can be called shales, for practically all of the beds contain considerable sand, and what is frequently called shale is actually a fine sandstone. There is no group of rocks in which a classification of rock types is more needed than in the Hamilton. For these reasons the writer has generalized the columnar sections, frequently indicating them to be composed mostly of argillaceous sandstone. It must be understood by the reader that the sequences are highly diversified as to lithology and must be illustrated later in sections drawn on a larger scale.

A note regarding the Bear Gulch section is also needed. The writer did not actually see any of the rock of this section between the Chittenango and the lower part of the Solsville members. In other words, the entire Otsego member was not seen. In the vicinity of Warnerville, Lawyersville and Richmondville, there has been some disturbance of the rocks, increasing the dip of the Onondaga notably. The average dip of the Onondaga in this region must be close to that determined in the Schoharie Valley. Consequently, the thickness of the Otsego was obtained on the basis of a dip of 137 feet per mile to the southwest.

United States National Museum,
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A SEMI-GRAPHICAL METHOD OF DETERMINING DEPTHS OF MULTI-LAYER, DIPPING STRATA FROM SEISMIC TIME-TRAVEL CURVES.*

SIDON HARRIS.

Although refraction *shooting* has been largely replaced by reflection *shooting* in the commercial field, it appears that theories and problems relating to the former type of seismic exploration are still of general interest. This fact is evidenced by recent papers which have been published on refraction *shooting*.[1,2]

The object of this paper is to describe a method of interpreting depths from seismic time-travel curves used by the writer on actual field data. No theoretical considerations are taken up and no new mathematical formulas are developed. However, the graphical method of solution is original, and has not been described in the literature to date. It was thought that a purely practical interpretation of seismic results would be of interest to the general reader.

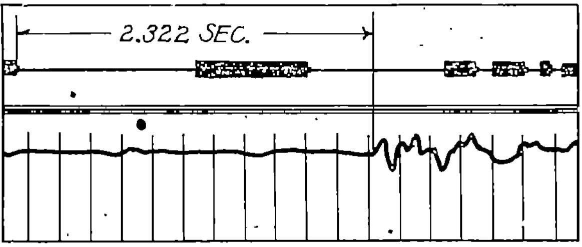

Fig. 1. A seismogram obtained by an electromagnetic type seismograph.

A section of a seismogram obtained from an electromagnetic seismograph used by the Humble Oil and Refining Company is shown in Fig. 1. The top line is recorded to indicate the time of firing of the charge of dynamite used to produce the shock waves. The buzzer break at the extreme left end of this line indicates the exact instant the charge was fired. The second line from the top has no significance, but the third line is the actual seismogram; i.e., it is a record of the velocity of the motion of the earth's surface in the vertical direction.

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* Published by permission of the Humble Oil and Refining Co.

[1] L. B. Slichter, *Physics* 3, 273, 1932.

[2] M. Muskat, *Physics* 4, 14, 1933.

The arrival of the first shock is plainly indicated. The vertical marks are time marks put on the record by a chronometer. The interval between marks is one-fifth of a second. By careful interpolation between these marks it is possible to read the time interval between the firing of the charge and the arrival of the first shock at the seismograph to .005 of a second. This time interval for the particular record shown in Fig. 1 is indicated on the record as 2.322 seconds; the last figure, of course, may be anywhere between 0 and 5.

The usual number of seismographs employed by a *party* is four. These instruments are placed at various distances from the *shot point* (the point where the dynamite is discharged), and the charge is fired; then the instruments are moved to new locations and another charge is fired. This process is continued until records are finally obtained with the instruments as far as six kilometers from the *shot point.* Cases are known where instruments were placed as far as 15 kilometers from the *shot point* and charges of 2,000 pounds of dynamite have been used. In one case, a charge of this magnitude was fired in the Gulf of Mexico, and the resulting shocks were recorded by instruments 15 kilometers away on the shore.

The records obtained are usually numbered A_1, A_2, A_3, A_4, for the first shot; B_1, B_2, B_3, B_4, for the second shot, and so on. For the first shot, the instruments are usually placed 50 meters apart and a 5-pound charge of dynamite is exploded; thereafter the stations are 500 meters apart and successively increasing charges of dynamite are used. Fig. 2 illustrates a typical profile obtained from seismic results shot over parallel, horizontal strata of successively increasing velocities of transmission of shock waves. The lower part of the figure is the profile of the stratification, while the upper part is the plot of the time travel curves obtained from the seismic data. The circles at each end of the surface represent the *shot points* Nos. 10 and 11, and the little triangles on the surface represent the various locations of the seismographs. The distances of these stations from their respective *shot points* are very accurately determined, and the time-travel curves are obtained by plotting the time required for the first shock to arrive at each station against the distance of this station from the *shot point.* It will be noticed that the curves obtained are a series of straight lines of different slopes. If the laws of optics are assumed to hold, it is easy to show that the reciprocals of these slopes are the velocities of transmission of the shock waves along the respective strata. The solid lines through the strata represent the *Mintrop shortest time paths* of these shock waves from *shot point* 10 to the respective stations, and the dotted lines represent these same paths for the shock waves from *shot point* 11 to the respective stations. In order to obtain the true velocities of the beds in the case of tilting, it is necessary to shoot in both directions. The first three points

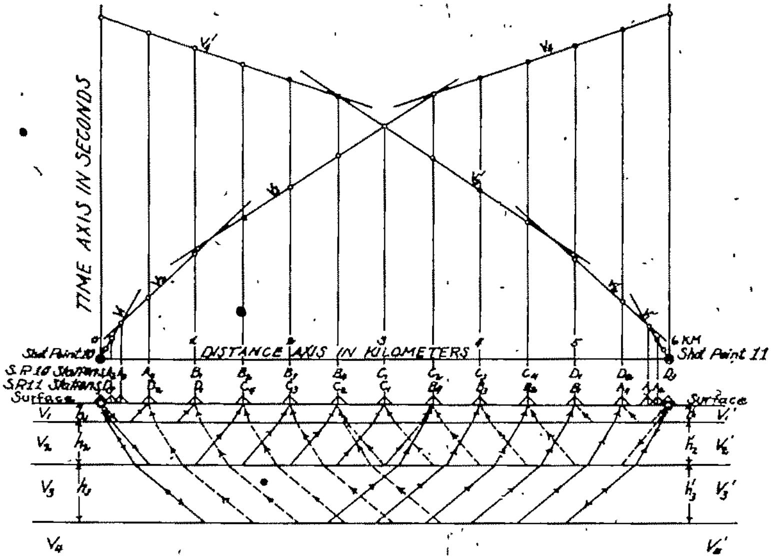

Fig. 2. A cross-sectional profile of horizontal strata, showing the *Mintrop shortest time paths* from *shot points* Nos. 10 and 11 to various receiving stations, and the resulting time-travel curves.

shown on the time-travel curve from *shot point* 10, show the time required for the shock to reach the stations by traveling along the surface; the fourth and fifth points show the time required for the shock to reach these stations by traveling through the first layer and along the surface of the second layer. For these last two stations it will be seen that less time is required for the transmission of the waves along the latter path than for the transmission of the waves along the surface. The sixth, seventh, eighth, ninth, and tenth points show the time required for the transmission of the impulses through the first and second layers, and along the surface of the third layer to the respective stations. It is seen that the time of arrival of the shocks refracted along the surface of the third and fourth beds is the same for the tenth point. The thicknesses and depths of the beds can be determined from the time-travel curves by substituting the proper values of X, T, and V in the following relations:

$$h_1 = 1/2 \cdot \operatorname{Tan} \alpha_4 (T_2 V_2 - X_2) \qquad \ldots (1)$$

$$h_2 = 1/2 \cdot \operatorname{Tan} \beta_3 \left(T_3 V_3 - \frac{2h_1}{\operatorname{Tan} \alpha_3} - X_3\right) \qquad \ldots (2)$$

$$h_3 = 1/2 \cdot \operatorname{Tan} \gamma_2 \left(T_4 V_4 - \frac{2h_1}{\operatorname{Tan} \alpha_2} - \frac{2h_2}{\operatorname{Tan} \beta_2} - X_4\right) \qquad \ldots (3)$$

$$h_4 = 1/2 \cdot \operatorname{Tan} \psi_1 \left(T_5 V_5 - \frac{2h_1}{\operatorname{Tan} \alpha_1} - \frac{2h_2}{\operatorname{Tan} \beta_1} - \frac{2h_3}{\operatorname{Tan} \gamma_1} - X_5\right) \ldots (4)$$

where the values T_2, T_3, T_4, and T_5 are the times of arrival of the first shocks at stations so situated at distances X_2, X_3, X_4 and X_5 from the *shot point* that these stations fall within the sections of the time-travel curves whose slopes are given by $1/V_2$, $1/V_3$, $1/V_4$ and $1/V_5$, respectively. The values of the angles used in the above relations are obtained from the following expressions:

$$\sin \alpha_4 = V_1/V_2 \quad \ldots . (5) \qquad \sin \gamma_2 = V_3/V_4 \quad \ldots . (10)$$

$$\sin \alpha_3 = V_1/V_3 \quad \ldots . (6) \qquad \sin \alpha_1 = V_1/V_5 \quad \ldots . (11)$$

$$\sin \beta_3 = V_2/V_3 \quad \ldots . (7) \qquad \sin \beta_1 = V_2/V_5 \quad \ldots . (12)$$

$$\sin \alpha_2 = V_1/V_4 \quad \ldots . (8) \qquad \sin \gamma_1 = V_3/V_5 \quad \ldots . (13)$$

$$\sin \beta_2 = V_2/V_4 \quad \ldots . (9) \qquad \sin \psi_1 = V_4/V_5 \quad \ldots . (14)$$

If a difference in elevation between receiving stations and *shot point* occurs, it is necessary to correct the indicated times of arrivals of the shocks for these differences in elevation.

Fig. 3 illustrates the case of a single inclined layer. In the case of an inclined layer, it is necessary to shoot a reversed profile; i.e., two profiles are shot over the same line: one up dip, and the other down dip. The depths, h and k, under the two *shot points* and the angle of dip θ are determined from the following relations:

$$h = \frac{T_2'' V_1 - X_2'' \sin(B)}{2 \cos \alpha \cos \theta} \qquad \ldots \ldots \ldots (15)$$

$$k = \frac{T_2' V_1 - X_2' \sin(A)}{2 \cos \alpha \cos \theta} \qquad \ldots \ldots \ldots (16)$$

$$\sin(A) = \sin(\alpha - \theta) = V_1/V_2' \qquad \ldots \ldots \ldots (17)$$

$$\sin(B) = \sin(\alpha + \theta) = V_1/V_2'' \qquad \ldots \ldots \ldots (18)$$

$$\theta = \frac{B - A}{2} \qquad \ldots \ldots \ldots (19)$$

where V_2' is the apparent velocity obtained from the slope of the time-travel curve shot up dip, V_2'' is the apparent velocity obtained from the slope of the time-travel curve shot down dip, T_2' and X_2' are coördinates of a point on the time-travel curve

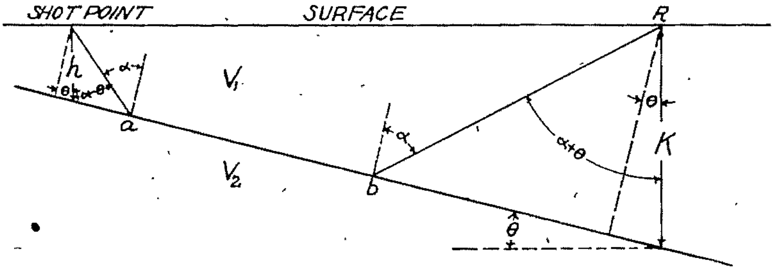

Fig. 3. A cross-sectional profile of a single dipping stratum with the *Mintrop shortest time* path from the shot point to the receiving station R.

shot up dip, and T_2'' and X_2'' are the coördinates of a point on the time-travel curve shot-down dip. The true velocity $\overline{V}_2$ of the inclined layer is obtained from the following relations:

$$\alpha = \frac{B + A}{2} \qquad \ldots\ldots\ldots (20)$$

$$\overline{V}_2 = V_1/\sin \alpha \qquad \ldots\ldots\ldots (21)$$

The equations (1)-(21) apply only where the velocities of the layers are all in an ascending order of magnitude from V_1 to V_n, and these equations are essentially the ones given by D. C. Barton in a paper entitled *The Seismic Method of Mapping Geologic Structure.*[8] However, if the area under consideration yields strata of several subsequent dips of different angles, the calculations become very complicated and it is quite laborious to determine the various dips, true velocities, and thicknesses of the beds from enlarging on the expressions (1)-(21). To simplify this problem, the following semi-graphical method was developed.

In most cases the thickness of the first bed can be calculated by the straightforward formula for parallel beds. The result, of course, gives the depth of the surface of the second bed only in the immediate vicinity of the *shot point* at each end of the profile. In general it may be assumed that the surface of this bed extends across the profile in a linear variation from the two *shot points*, and that this bed has the seismic velocities at each end of the profile indicated by the time-travel curves. It must be remembered that the dip formulas can be used only where either the true velocity of the dipping bed is known or where the reversed profiles overlap. Suppose the surface of the third bed indicates a dip of θ_1 degrees with the horizontal surface. As the true velocities of the first two beds are known, and as the surface of the second bed is parallel to the surface of the ground, the true velocity and dip of the third bed may be determined from the following relations:

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[8] D. C. Barton, *Geo-Physical Prospecting for 1929*, page 572.

$$\theta_1 = \frac{B - A}{2}, \text{ where } \sin B = V_2/V_3'' \qquad \ldots\ldots(22)$$

$$\sin A = V_2/V_3'$$

where V_3'' is the apparent velocity down dip, and V_3' is the apparent velocity up dip.

$$\overline{V}_3 = \text{true velocity} = V_2/\sin(A + \theta_1) \qquad \ldots\ldots(23)$$

It now remains only to find the thickness of the second bed under each *shot point*. First, calculate the angles of refraction for the *Mintrop path* refracted along the surface of the third bed by using relations (6) and (7), and lay off the path accordingly for a station on the V_3'' and V_3' curves. Then, measure the path length through the first layer and determine the time required to traverse this layer by dividing the path length by the velocity V_1. Subtract this time interval from the time coördinates of the chosen points on the V_3'' and V_3' curves and use the remainders as the values of T in relations (15) and (16). It must be remembered that the values of X used in the calculations of h and k are the distances of the stations chosen from the respective *shot points* minus the mirage distances on the surface of the V_2 layer. The mirage distance is illustrated by the distances ab and pq in Fig. 4.

Suppose the surface of the fourth bed has a dip. On account of the dip of the third layer, the slopes of the time-travel curves of the fourth bed will be affected whether the fourth bed has a dip or not. In order to remove this effect of the third bed the following procedure is taken. Assume a true velocity for the fourth bed; a mean value between the velocities obtained from the up and down dip time-travel curves is usually a fair approximation. Calculate the angles of diffraction of the *Mintrop path* diffracted from the surface of the fourth bed, using the assumed velocity for V_4 in the relations (8)-(10), and lay off the parts of the path through the first and second layers for at least two points on the up dip profile and the same number on the down dip profile. Calculate the time required in traversing the first and second beds for each of these points and subtract the corresponding time interval for each point. Then draw the two new time-travel curves through these points. The slopes of these two new curves will give the dip of the surface of the V_4 bed relative to the surface of the V_3 bed. The above action will, of course, rotate the plot of the time-travel curves through an angle θ so that the abscissa, or distance axis, will be parallel to the secondary surface, which is the surface of the V_3 layer, and the coördinates of the time-travel curves must be read accordingly. With this action accomplished, the procedure is the same as for the case of a single dipping layer. The dip angle calculated in the usual manner will be the angle of dip between

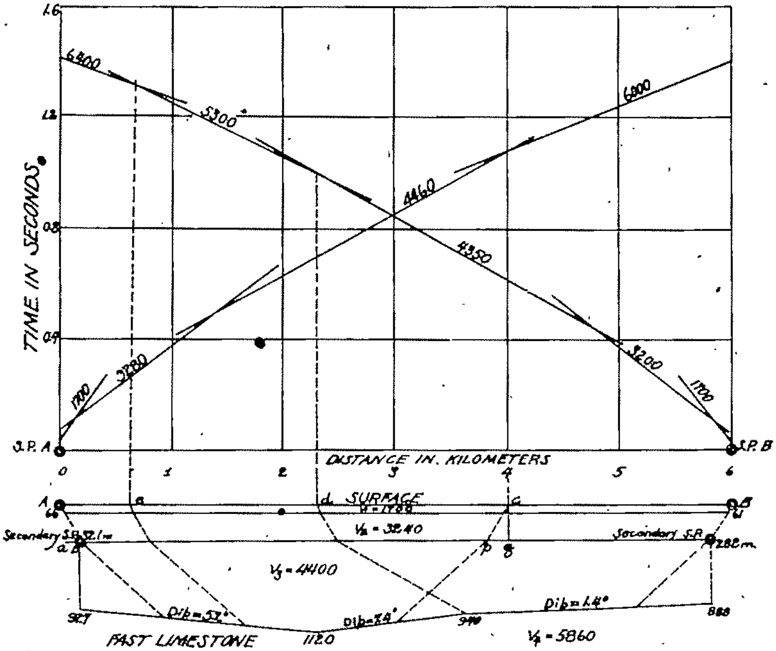

Fig. 4. The time-travel curves obtained from actual data taken from records shot in an area in West Texas, and the resulting profile calculated according to the method described in this paper.

the surfaces of the V_3 and V_4 beds, and the values of h and k will be the thickness of the V_3 bed under the secondary *shot points* on the surface of this bed. The true velocity of V_4 can be calculated in the same manner as $\overline{V}_3$ was previously determined; and if the result is not in good agreement with the assumed value of V_4, a new value for this quantity can be assumed and the entire procedure repeated. A high degree of accuracy can be obtained by repeating this procedure a few times. The writer has obtained numerous checks which were well within the experimental error on the first round.

A certain area yielded the time-travel curves illustrated in Fig. 4. The velocities in meters per second are as indicated on the curves. The scale of plotting is, of course, greatly reduced from the work sheet. From the curves, it is apparent that there are four beds represented; the velocities of the fourth bed indicated from *shot point* B show definitely a hole in the surface of the high speed bed. It should be stated that before any depth determinations were made from this profile, a careful consideration was made of the characteristics of the beds throughout the entire region under investigation. A total of six profiles were shot on this particular region. It would be very hard to determine the true velocity of the high speed bed from the profile illustrated in Fig. 4, but from another profile shot in the same vicinity which was more regular, a normal of 5860 m./sec. was fairly well defined for the lower bed. In the calculations of the dips of this bed the 5860 m./sec. true velocity was used. The fact that the V_1 curves in Fig. 4 do not pass through the origins at each *shot point*, is explained by the fact that the shots were fired from the bottoms of small wells 50 feet deep. This discrepancy may be corrected by pushing up the distance axis so that the V_1 curves will pass through the origins at the two *shot points*.

The thickness of the first bed under each shot was determined by using the values of V_1 and V_2 written on the time-travel curves at each end of the profile in equation (5), and by substituting the proper coördinates of points obtained from the V_2 curves in equation (1). The results are written on the subsurface chart shown in Fig. 4. The surface of the third bed showed a dip down towards *shot point* A. It was within the limit of accuracy of the data to take a mean between the values of V_2 given at each end of the profile as the true velocity of the second bed, i.e., $\overline{V}_2 = 3240$ m./sec. The angle of dip of the surface and the true velocity of the third bed were determined by using relations (22) and (23). The thickness of the second bed under each *shot point* was determined by the method previously described.

The surface of the fourth bed, which was of principal interest in this case, was obtained in the following manner. As the true velocity of this bed was known from additional data, no true velocity determination was necessary. From the time-travel curves refracted from the surface of the bed under consideration, it is apparent that there were three distinct dips. The dip angle of the surface of V_4 with the surface of V_3 under *shot point* A was determined as follows:

$\sin A = 4400/6400 = .687,\ A = 43.4°$
$\sin(A + \theta) = 4400/5860 = .750,\ A + \theta = 48.6°$
$\theta =$ dip angle $= 5.2°$ down from *shot point* A.

The dip down from *shot point* B was determined in a similar manner and was found to be 1.4°. It is seen from the time-travel curve that a dip downward on the *shot point* B profile occurs between stations d and e (Fig. 4). This dip was calculated to be 7.4° by the same method as the other dips were determined. The thickness of the V_3 bed is unusually difficult to compute in this case as the surface of the V_4 bed is not on a steady dip between the two *shot points.* The method used here is essentially a cut and try method, but it must be remembered that all geophysical interpretations are largely accomplished by setting up conditions which will give the observed results. By using 5860 as the value of V_4 in relations (8)-(10) the angles of refraction of the *Mintrop* paths were determined and the paths laid off as shown in dotted lines in Fig. 4. From other profiles of more regular character, the depth of the V_4 surface at each end of the profile in question was found to be nearly the same. The time required to traverse the V_1 and V_2 beds along a path through the V_4 bed from *shot point* A to *shot point* B was determined by measuring the sections of this path through V_1 and V_2, dividing the results by the respective velocities, and the result was found to be 0.254 seconds. The correction for X, which was the sum of the distances from the actual *shot points* to the respective secondary *shot points* on the surface of the V_3 bed, was found to be 350 meters. The value of T was determined by subtracting 0.254 sec. from the time coördinate of the point at the end of each profile. This time coördinate was, of course, the same

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for both end points. The thickness of the V_3 bed under each *shot point* was then determined by substituting the corrected values of X and T in relation (1) with the values of V_4, T_4, and X_4 being used in place of the values of V_2, T_2, and X_2. The thickness of the third bed under each *shot point* came out to be 606 meters. The depth of the V_4 surface in the immediate vicinity of each *shot point* was thus determined and plotted on the sub-surface chart as shown in Fig. 4. By drawing lines through the depth points at angles previously determined, the surface of the V_4 bed was obtained at each end of the profile. The slope of the V_4 surface which connects the dips at each end of the line was previously determined to be 7.4°. From the seismic times of the stations marked d and e on the surface, it is apparent that the sharp dip occurs between d and e. Hence, by drawing in the 7.4° dip from the surface of the V_4 bed at the point where the path through d intersects the line drawn from *shot point* B, and extending this line to intersect the 5.2° dip line drawn from *shot point* A, the surface of the high speed bed was completed.

A good method of checking the work is to select some point which lies on one of the V_4 curves and trace its path from the station to the *shot point*. By measuring the sections of this path and dividing them by their respective velocities, the time of arrival of the first shock at the station located on this path is computed. This calculated time should check the seismic time on the time-travel curve. Several checks of this sort were made when the profile illustrated in Fig. 4 was first computed. All the checks came within .005 of a second of checking the data. This accuracy was within the limits of error of the instruments, which were Petty[4] condenser type seismographs equipped with a string galvonometer recording system. Chronometer marks were made on the seismograms which enabled the time of arrival of the first shock to be read to .005 seconds.

In summary, it will be seen that in order to arrive at any satisfactory conclusions as to the depths of consolidated deposits from refraction shooting, it is necessary to shoot extensively over the area under consideration and then plot the entire data and arrive at approximate true velocities of the deeper beds, before attempting computations of depths. Then each profile must be taken up separately and a rough

[4] Made by the Petty Geo-Physical Corporation, San Antonio, Texas.

contour of the sub-surface bed of most interest (usually the deepest one) sketched from the time-travel curves before actual calculations are started. This procedure gives the computer an outline to work from, and is of great aid in keeping the results within reason. In the case of the example illustrated in this paper, all six profiles were worked out and a sub-surface contour map made of the limestone surface. The contour map showed a decided ***high*** in the surface of the limestone. This ***high*** was later drilled into and the difference between the well log and the calculated depth of the ***high*** was only 4% of the calculated depth.

The fact that McCollum and Snell[5] found that the velocity of the *sound waves* is not the same in all directions in consolidated deposits introduces an error in the method described in this paper. However, if the velocity across the beds is determined from other methods, these values can be used in determining the time required to cross the beds. It might be said that in regions similar to the one illustrated in this paper, the method described here was found to check admirably with later determined well logs, and it is doubtful if the difference in the velocity of the shock waves across and along the beds in these cases was very pronounced, or that they introduced a serious error in the results.

In support of the method just described, it may be said that it facilitates mathematical work to a high degree, enables the computer to break up the problem into sections which aid him in placing the observed time differences of the records in their proper places in the sub-surface chart, and checks to a close margin calculations made from much more lengthy derivations.

I wish to express my appreciation to Mr. J. E. LaRue of the Humble Oil and Refining Company for permission to publish this article.

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[5] McCollum, B., and Snell, F. A., *Physics* 2, 174, 1932.

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CANYONS OFF THE NEW ENGLAND COAST.*

FRANCIS P. SHEPARD.

INTRODUCTION.

During the summers of 1931 and 1932 I had the opportunity to accompany Coast Survey vessels during most of their charting of a 200 mile stretch of the continental slope off Georges Bank. This area extends east from a point 100 miles south by east from Cape Cod and 40 miles south of the Nantucket Lightship. Along this slope submarine canyons of awe-inspiring proportions were discovered. Prior to the Georges Bank survey there was almost no indication of these canyons, but at present some of them are more completely charted than any other deep submarine valleys in the world. There is every reason to believe that if these features were visible they would compare scenically with the most impressive canyons in the world.

Distribution and Character of the Canyons.

The general distribution of the submarine canyons along the 200 miles of continental slope is shown in Fig. 1. The scale of this contour map has prevented the drawing of details and except for the 300-foot contour line it was found advisable to use a 600-foot interval. It seems probable that there are various undiscovered valleys in the eastern portion of this map where soundings were less numerous than elsewhere. It will be observed that some of the valleys indent the continental shelf while others do not extend above the continental slope. In no case does a valley penetrate more than 12 miles into the continental shelf and the 50-fathom contour shows almost no relation to the valleys.

These submarine canyons are by no means limited to the upper parts of the slope. They all extend down to depths of at least 6000 feet below sea level and in no case does the survey attain great enough depths to show their outer termini. The greatest depth observed in one of these canyons is 8400 feet. Below the adjacent slopes they are cut to depths ranging up to about 4500 feet, 7 of them being incised more than 2500 and 24 others more than 1000 feet.

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* The writer wishes to express his appreciation for privileges extended to him by the U. S. Coast and Geodetic Survey. Also thanks are due to Mr. George Cohee for the analysis of some samples of sediment, and to Dr. R. B. Stewart for an opinion of a fossil.

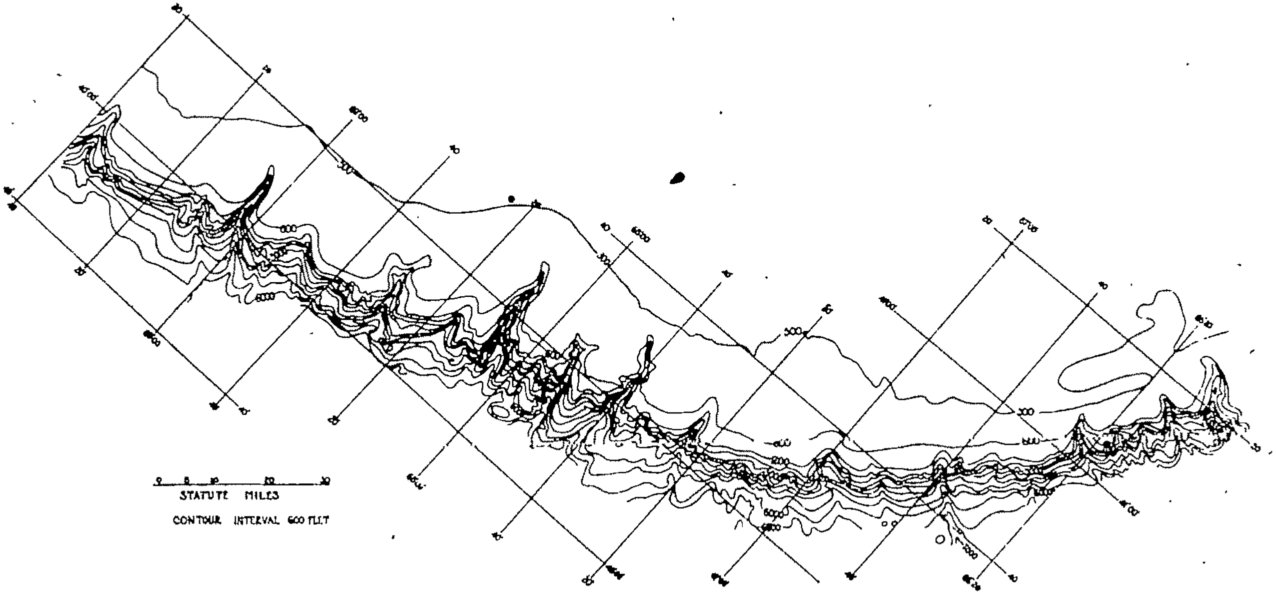

Fig. 1. Showing the distribution of canyons along the continental slope off Georges Bank.

The characteristics of the canyons are shown best in the maps of larger scale. An impressive group discovered during the summer of 1932 was surveyed in great detail (Fig. 2). Accurate determination of positions was made by dropping bombs at frequent intervals from the surveying ships. The sound from the explosions when received by two anchored station ships was relayed back by wireless and the time interval gave the distances. Where the sounding lines were well separated the contours are, of course, less accurate but their approximate nature was determined from the general character of the adjacent topography. Taken all in all the contours are probably as accurate as those of the older topographic maps of our western mountains. The established points are, of course, much more numerous in this marine survey, but this is offset by inability to see the features and by the fact that echo soundings on a slope somewhat minimize the depth and soften the relief. This last point makes it probable that these canyons are actually more impressive than is indicated by the map.

Resemblance to River Valleys.—The canyons have many features in common with those land valleys which have been cut by rivers. Their courses are undoubtedly sinuous probably more so than is shown on the maps. Curiously, most of the larger valleys have a gently curving Z-trend like that of the Hudson submarine gorge. The valley bottoms slope outward practically continuously and take directions such as might be expected of streams working down the slope towards the abyss. The tributaries come in with the dendritic pattern characteristic of land valleys. In cross section the submarine valleys are roughly V shaped, particularly in the upper portions and have very steep walls (Fig. 3).

Origin of the Canyons.

Faulting and Submarine Currents.—In recent years various authors have attributed submarine valleys either to faulting or to submarine currents.[1] If these canyons were due to faulting they should have the straight walls and trough shapes characteristic of fault troughs. Probable fault troughs are found at the base of the continental slopes in many places, but these trend parallel to the slopes and not at right angles as

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[1] The writer has recently discussed the various hypotheses concerning submarine valleys giving rather complete references to the literature on the subject. Submarine Valleys, Geog. Review, 23, 77-89, 1933.

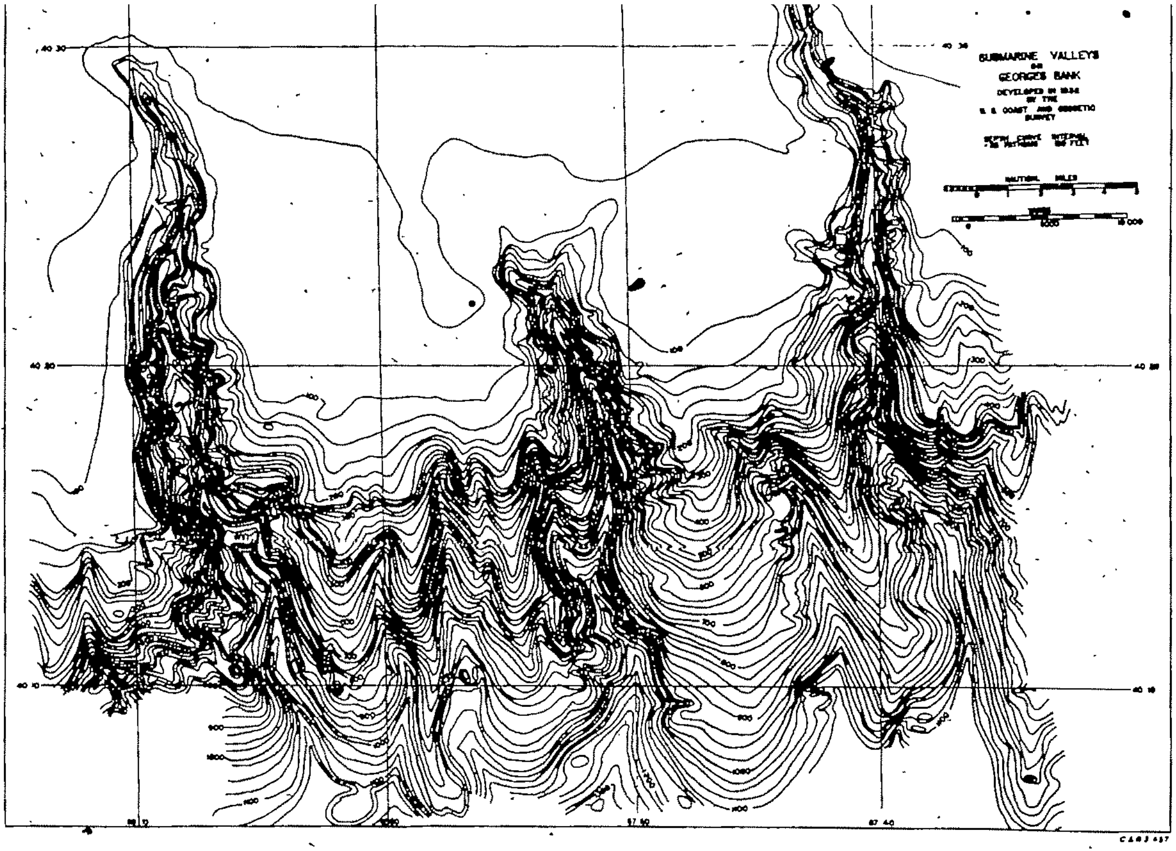

Fig. 2. The canyons which were surveyed in greatest detail. These contours are based on what is probably the best deep water survey in the world at the present date. The writer will be glad to send the original sheet with soundings to any one interested.

do the submarine canyons. If the canyons were cut by submarine currents, such currents must have been unbelievably powerful. Judging from their high precipitous walls the canyons must have been cut in solid rock. Such walls, if made of unconsolidated material, would have caved in especially if subjected to earthquake shocks like that of 1929. Current data show that at least the surface currents have the greatest flow at right angles to the canyons on the outer portion of the shelf in this vicinity. Bottom forms on the shelf suggest the

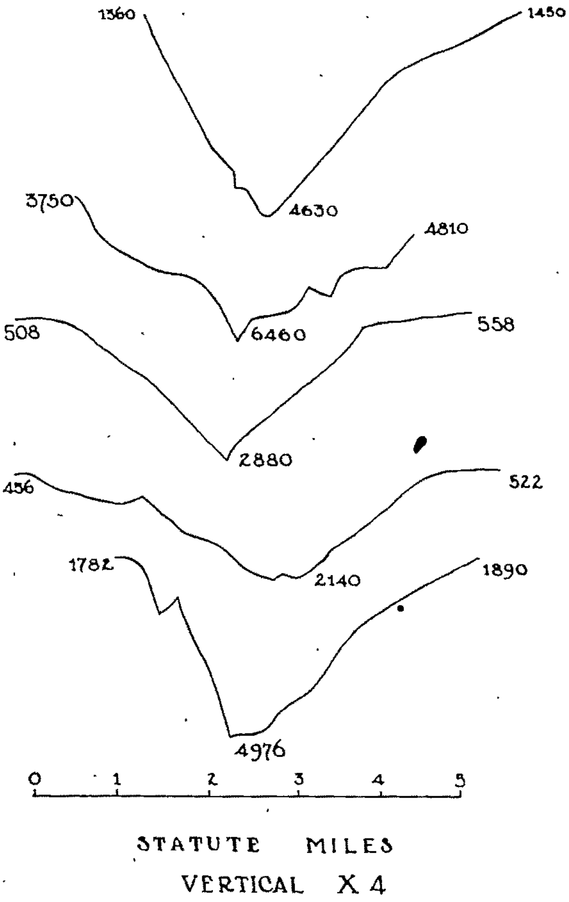

Fig. 3. Showing the rough V-shaped transverse profiles characterizing the canyons of figure 2.

TABLE I.

Showing the analyses of specimens in and around the submarine canyons. It will be observed that the $CaCO_3$ content is about the same in the base of the canyons as on the outer part of the adjacent continental shelf. Also it is noteworthy that there is more coarse material in the deepest sample within the canyons than in the others. The specimen from the side of a canyon was a consolidated sediment. Analyses were made by George V. Cohee.

	Lat. Long.	Depth (fathoms)	$CaCO_3$ content	Gravel 2 mm. plus	Sand .25 mm.-2.0	Sand .074-.25 mm.	Clay-silt under .074 mm.	Heavy Minerals
Base of submarine canyon	40 16′ 68 06′	725	7.55%	.67%	7.04%	27.75%	56.97%	.5%
Base of submarine canyon	40 19′ 68 08′	520	1.25%		.49%	1.61%	89.40%	.02%
Base of submarine canyon	40 19.3′ 68 07′	411	9.0%		10.3%	12.2%	68.0%	5.46%
Base of submarine canyon	40 18.4′ 68 09.3′	256	2.4%		1.7%	4.4%	91.35%	.02%
Side of submarine canyon	40 23′ 67 55′	150	40.0%	8.7%	48.7%	.6%		.01%
Shelf inside of canyons	40 25′ 67 55′	77	7.91%		57.3%	33.6%	3.73%	7.0%
Shelf inside of canyons	40 33′ 68 23′	50	6.02%	.3%	14.68%	70.01%	4.02%	1.8%

same trend.[2] Furthermore, quiet conditions must exist on the bottoms of the canyons to allow the accumulation of the fine sediments which are found there. These sediments consist predominantly of clay and silt (see Table I), which is in contrast to the coarse sediment characterizing the continental shelf inside.

Submerged River Valleys.—It seems to be a reasonable assumption that canyons like those described above were cut by rivers, but this explanation is fraught with many difficulties. If the continental shelf was much higher recently there should be evidence of this uplift on the lands. Also the charts show that the continental shelf in this region has marginal depths which average about 70 fathoms. These depths are characteristic of shelf margins over much of the world and suggest that the shelves possessing them developed under stable conditions. If these canyons have been submerged for thousands of feet how can the shelf be in equilibrium?

Pre-shelf Submergence of the Canyons.—If the canyons were submerged in the remote past and the continental shelf was cut afterwards, the difficulties suggested above would cease to exist. On the other hand a new difficulty would arise. As soon as the canyons had become submerged they would have been subject to filling by sediment from the surrounding lands. During the cutting of the continental shelf the wave erosion and subaerial denudation would have provided vast quantities of sediment for the filling of the submerged canyons. Still later, when glaciers stood on the north side of Georges Bank,[3] there must have been an abundance of outwash carried into the submerged canyons by streams crossing the exposed continental shelves of glacial times.

Canyons Reopened by Landslides.—Filling of the canyons by sediment is not necessarily fatal to the idea that the canyons were cut prior to the shelf origin. The valley fills might have been removed subsequently by landslides of a mud flow type. Conditions are particularly favorable for such action at the margin of the continental slope. These slopes have here, as elsewhere, much the appearance of fault scarps and are subject to earthquakes. The fine sediments which accumulated in the valleys would slide easily under conditions of saturation. The gradients in the valley floors, averaging 300 feet per mile, are sufficiently steep to allow the sliding of muddy material.

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[2] On the northern portion of the bank the currents trend northwest southeast producing elongate shoals in that direction, but this changes further south to northeast southwest.

[3] Proof that the glaciers extended onto Georges Bank was obtained from bottom samples of till obtained by the writer on trips with Coast Survey vessels.

Evidence which I have presented elsewhere[4] suggests that slides may have modified submarine valleys in recent years.

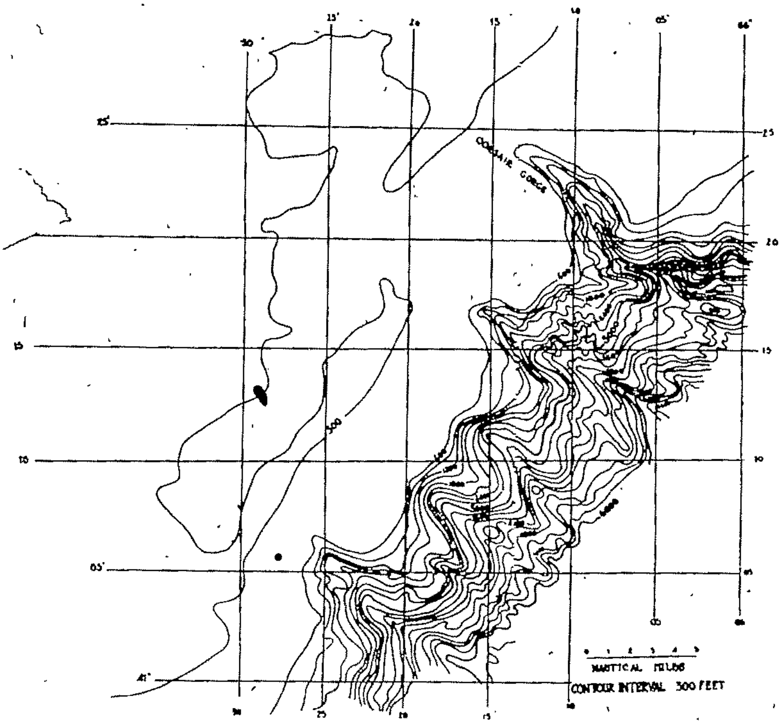

Fig. 4. Showing some canyons on the eastern portion of the slope including Corsair Gorge which is thought to have been opened by a landslide in 1929 at the time of the Grand Banks earthquake.

There is reason to believe that Corsair Gorge (Fig. 4) was opened at the time of the Grand Banks earthquake in 1929.

If large quantities of sediment have slid out of the valleys, there must be accumulations outside on the deep ocean floor and perhaps to some extent in the outer portions of the valleys. Where these accumulations had piled up into high mounds like those of landslides on land they might be found by closely spaced soundings. Unfortunately, data are not available beyond the canyons to check this point, but there are some suggestions of hills in the outer canyons which may have originated in this way.

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[4] Landslide Modifications of Submarine Valleys. Trans. Amer. Geoph. Union, pp. 226-230, 1932.

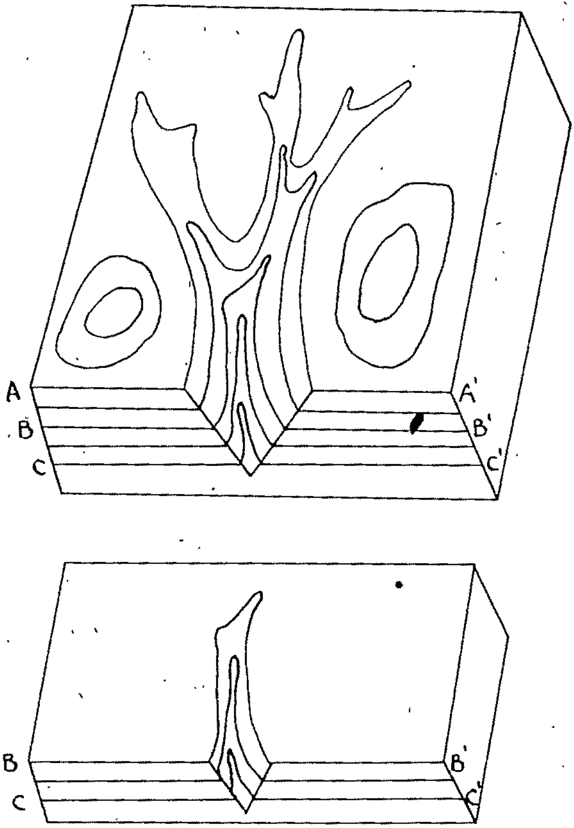

Fig. 5. Illustrating how the branching head of a canyon might be changed by levelling of the upper portions after submergence to level B-B'.

Mud flows moving into the outer canyons may have filled in the V-shaped bases and have left fairly smooth surfaces like that of the Slumgullion flow in Colorado. Some of the places where there is evidence of a broadening of the base of the canyons may be explicable in this way.

Landslides as the Entire Cause.—I have been asked whether the submarine valleys could have been formed entirely by landslides, obviating the difficulty of the river cutting part of the hypothesis. I feel that there are various reasons for believing that this could not have been the case particularly in regard to the canyons under discussion. Their shapes are entirely different from the lunate scars which are left after the breaking away of a mass of rock or sediment from an escarpment. Since it appears highly probable that the canyon walls are made of rock, it becomes inconceivable that masses of solid rock could have slid from the shelf and slope leaving these elongate, sinuous, steep-walled canyons. On the other hand it is perfectly reasonable to suppose that slides could carry away the loose sediment filling a rocky gorge.

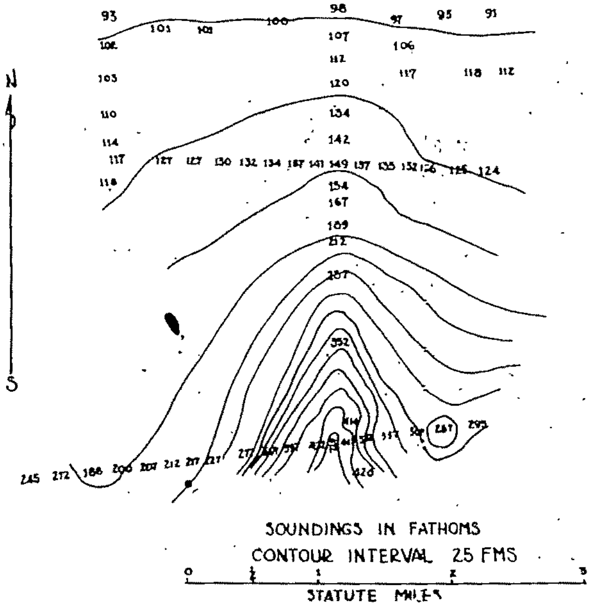

Fig. 6. Showing the broadened and flattened head of a canyon which terminates below the outer edge of the continental shelf.

Valley Heads.—The headward terminations of the submarine canyons differ from those of land canyons in that the former have fewer tributaries and more abrupt ends. This difference may be due to the erosion which is thought to have followed the canyon submergence and which would have cut away the valley heads and have left only their trunk portions (Fig. 5).

Another less usual type of canyon head is shown in Fig. 6. Here a V-shaped valley broadens out at its head into a gentle amphitheatre which does not truncate the continental shelf at all. A possible explanation of this case is that the inner portion of the valley is not yet cleared of sediment or that in the interval since a landslide evacuated this valley sediment has started to fill in its head.

Land Movements Preceding Landslides.—Under the circumstances it seems probable that the canyons were first cut by rivers, then filled with sediment, and finally reopened by landslides. It is not reasonable to suppose that the sea level could have been lowered 8000 feet or more allowing rivers to flow down these slopes so we must conclude that the lands were greatly elevated at some time during the past. At this time New England, or at least the continental shelf east of New England, must have been either a high plateau or a mountain range. It would appear from the steepness of the valley walls and from the high gradients that this land was not reduced to a low relief before submergence. The uplift must have been of relatively short duration.

Time of Canyon Cutting.

Possible Association with Appalachia.—The time when the canyons were excavated is not easy to determine. The area was probably greatly elevated during the late Paleozoic when the conglomerates of eastern Massachusetts and Rhode Island were being derived from a source to the east.[5] In later times there does not appear to be any indication that the area under discussion was greatly elevated. Accordingly, we are confronted with the possibility that these canyons were cut into the seaward flank of Appalachia. If such were the case the land mass must have been down-faulted before erosion could have greatly modified the canyons. They may have been maintained since then by repeated landslides which prevented the consolidation of the sediments accumulating in the valleys.

Old Continental Outlines.—If the above suggestion is correct, it would appear that at least in this area the old east slope of Appalachia is now represented by the continental slope. Here we have a suggestion that the old continental outline was not far different from that of the present provided we consider the true continental border which is the margin of the continental shelf. A narrower Appalachia would do away with the difficulty of explaining the engulfment of a continental borderland into the oceanic abyss. The narrower Appalachia might have provided the required amount of sediment for the Appalachian geosyncline provided it were uplifted a sufficient number of times. However, before carrying this speculation too far we need more evidence that the canyons were formed in these remote times. It seems not inconceivable that such evidence might be found by oceanographic investigations.

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[5] J. B. Woodworth, The Appalachians in Southern New England. Bull. Geol. Soc. of Amer., 34, pp. 257, 1923.

Possible Tertiary Age.—It is also quite possible that the submarine canyons are much younger, perhaps of Tertiary age. It has been suggested by Joly[6] that the continents are periodically rejuvenated. If whole continents are uplifted at certain times, valleys may be cut in their margins and later submerged. This wholesale uplift, unlike the elevation of marginal tracts, would not cause sediment to be washed inland. Also, this explanation has some appeal because deep submarine valleys are found off all of the continents of the world. Yet it is hard to believe that the continents could have been uplifted en masse to elevations of one or even two miles above the present levels.

Fossil Evidence.—Future hope for determination of the age of submarine valleys may lie in the collection of bottom samples particularly from the steep walls of canyons. Support of this contention was found during the surveying of the canyons off New England. Only a few samples were procured, but of these one contained a poorly preserved fossil. Near the head of one canyon four bottom samples were collected from the same wall at depths ranging from 195 to 105 fathoms. In each case fragments of the same rock formation were collected. These consisted of well rounded and sorted quartz sand and small quartz pebbles cemented by calcium carbonate. The latter made up about 50% of the formation. The fossil collected at 195 fathoms was diagnosed by Dr. R. B. Stewart as probably Tertiary in age. The formation is strikingly different from the aequeo-glacial sands and gravel which cover the shelf adjacent to the canyon heads. The pureness of the quartz and its well rounded character, together with the insignificant amounts of heavy minerals (Table I) are all proof that the formation was not formed from material which slumped down from the shelf above. It seems possible that the formation was derived from the weathering of quartz-bearing rocks during the submergence of the canyons. The deposition of calcium carbonate at the same time under conditions different from those now existing could have cemented this material together.

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[6] John Joly, Surface History of the Earth, p. 56 1925.

Conclusions.

We may conclude that the submarine canyons off New England are quite certainly of fluvial origin. The uplift which allowed the canyon cutting was clearly prior to the formation of the continental shelf in this vicinity and may have been as remote as the late Paleozoic. The canyon walls are almost certainly solid rock, indicating that the continental shelf here has been the product of erosion rather than of building up by sediments from the lands. The canyons are thought to have been filled with sediment in whole or in part, but are preserved in outline, by the evacuation of the sediment through the agency of landslides.

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To avoid injury by the blasting to whatever minerals might be present, work was begun on the outer edge of a half circle about ten feet in radius described about the original find, and a pit was sunk in the solid graphic granite of the dike some eight feet in depth. It was possible, by constructing a syphon, to lower the water level in the quarry to this depth. As depth was gained the mineral focus was carefully developed and finally opened out into a large pocket, the dimensions of which were ultimately found to be about four feet by six feet in

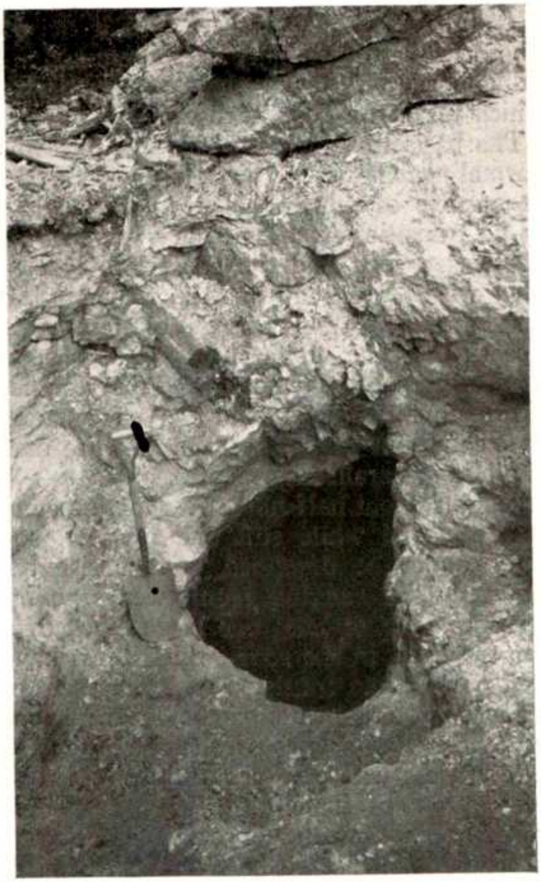

Fig. 1. The topaz pocket, Topsham, Me. The shovel is about 3½ feet long. The surface of the old quarry floor where the first opening was found is shown at upper left corner of view.

cross section and about six feet high. The pocket was lined throughout, with an exception to be presently described, with heavy layers of cleavelandite feldspar, the plates normal to the wall and the layers from two to nine inches thick. In parts this lining was as much as eighteen inches in thickness. Generally on its outer border there was a development of lepidolite both in masses of platy crystals mixed with cleavelandite and as borders replacing the outer layers of muscovite crystals which reached a foot in diameter but were generally smaller. The basis to which the cleavelandite was attached was the normal graphic intergrowth of quartz and microcline with large garnets of which this part of the dike consists. There was no transition—the boundary was sharply marked. The pocket was domed and the roof, largely cleavelandite, was studded with groups of quartz crystals, clear, smoky, sharply formed and with no signs of solution or etching.

The exception to the albite lining of the pocket was a narrow band in the roof which consisted of fresh flesh-colored microcline quite unaltered except at the very surface, where it showed an etching-out of the perthite lamellae and an overgrowth of albite in parallel aggregates.

The pocket was about half filled with loose material. Most of this was removed while still under water, so its exact arrangement cannot be described. It consisted of quartz crystals of every size ranging from twenty pounds' weight down to an inch long or less; one large block of microcline like that of the band in the roof, which must have weighed one hundred pounds and consisted of a fragment of a single crystal; many small fragments of the same mineral more or less altered to sericite; masses of cleavelandite of every size and shape, doubtless wall fragments; and a great assortment of small fragments of material to be later described. All these were embedded in mud or clay. The least disturbed parts of the pocket seemed to be filled with perfectly plastic white kaolin. The surface mud was gray, probably discolored by infiltrated surface material. All this material, certainly a ton or more, was removed by hand to avoid breakage. The mud was taken in buckets to the quarry pool and washed on a screen and the fragments thus revealed were carefully examined.

The materials obtained were extremely diverse and showed a wide range of chemical attack. Quartz crystals and cleavelandite alone were wholly unetched. They constituted, especially the latter, the majority of the fragments. Next in abundance were irregular shells of dense sericite and vein fragments of lepidolite or clusters of crystals of the same. Topaz was next in abundance. The largest crystal weighed just under three pounds and several others but little less, the greater portion being in small crystals. All, except two crystals, were deeply etched. Beryl was found in one spot only, where several pounds of deeply etched fragments, colorless or of a pale rose color, were taken from the mud. Thousands of slender crystals of blue tourmaline were found, rarely thicker than a stout knitting needle, up to two inches long, singly terminated. Gahnite or zinc-spinel was a minor constituent. A single crystal of apatite was found, and this was the only phosphate present except for herderite, which was far less abundant, relatively, in the pocket than it had been near the surface.

By the time the bottom of the pocket was reached the water-level had gone down so that it was possible to examine the floor in detail. It consisted of horizontal layers of albite exactly like the walls and roof and, on blasting through it, it was found to rest on fresh graphic granite exactly as did the walls. The beryl and larger topaz crystals were found in narrow lense-like pockets where, near the floor, layers of albite gaped apart. The topazes were loosely attached and seemed to have grown in these restricted openings.

I am writing these details of the structure of this pocket now while the memory of each of them is fresh. The crystallographic and chemical study of the minerals found must await study and will be presented in a later paper. But something can be said of each of them from observations made as they came to light.

Albite:—Albite in the platy form known as cleavelandite is the most abundant material in the pocket. Generally the plates are densely packed together in fan-like aggregates. The surfaces of blocks and layers composed of it are well crystallized and remain bright and unetched. Locally the albite plates intersect in a coarse net-work leaving open spaces from whose walls crystals of albite, quartz, lepidolite, tourmaline and gahnite project. In the lower part of the pocket the albite is often coated with a dense layer of pinkish sericite, from a quarter of an inch to an inch in thickness. Generally this coated and did not replace the albite; but often the albite beneath such layers is kaolinized and needles of tourmaline project into the cavities or porous spaces so formed. Complete shells of this sericite were among the commonest products of the pocket mud. They are sometimes traversed by delicate veinlets of translucent lepidolite. Direct albitization of microcline and quartz was observed at a very few points.

Quartz:—Crystals of quartz are attached to the albite of the roof, and were lying loose in great numbers in the pocket mud. The largest loose crystal was flattened parallel to a pair of rhombohedral faces, measured about a foot across with a thickness of three inches, and showed no point of attachment. The crystals are simple in form and are slightly smoky in color. They show almost no sign of etchi Hundreds of small crystals were recovered from the m generally complete individuals and as a rule much distort by flattening parallel to a pair of faces, either prisms rhombohedrons. While quartz had generally formed after th albite had ceased to be deposited, there were a few specimens found where a quartz crystal had started to grow near the beginning of the formation of an albite layer and had prevented the deposition of albite upon it, so that it now appears at the bottom of a cylindrical pit in the later albite. Quartz was found enclosed in beryl and topaz, although but rarely; and one minute crystal was seen perched on an etched surface of topaz. But, as a whole, its deposition was finished before beryl and topaz formed.

Topaz:—Of the hundreds of topaz crystals recovered from the excavation only two were sufficiently free from etching to reveal their original form. One of these was doubly terminated, about three-quarters of an inch long, perfectly symmetrical, and bounded by the forms $l(120)$ and $y(041)$. It was found near the surface embedded in lepidolite. The other was larger, about three inches across, and was found in the bottom mud. It showed a broad surface of fresh cleavage and probably had been broken from the roof, but the place of attachment was not found. This crystal showed a more usual topaz habit with faces of the prism zone, two pyramids $u(111)$ and $i(223)$, and the brachydome $y(041)$. With these exceptions the topaz crystals are but remnants of the originals both in form and size, varying from thin shells or skeletons bounded wholly by etch planes to crystals still preserving parts of the brachydome faces of $y(041)$, but otherwise so attacked by active solvent action that all crystal faces are destroyed

(Figure 2). The largest crystal remnant weighs about three ounds and measures four by four by five inches in the directions of the *a*, *b*, and *c* axes respectively. One fairly symnetrical crystal found in place on a mass of sericitized microline measures four and half by three by six inches (Figure 3). The whole mass of topaz recovered weighed twenty-five ounds, about half of this amount being accounted for by six rystals each a pound or more in weight.

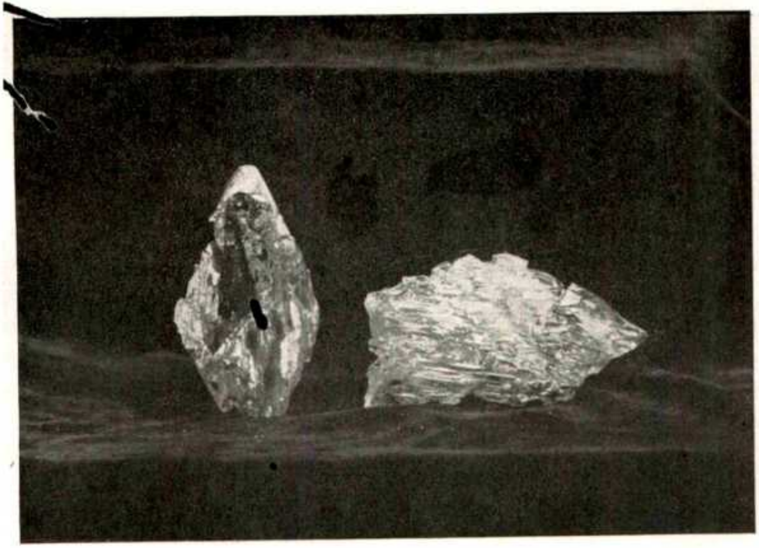

Fig. 2. Topaz crystals, Topsham, about ⅓ natural size. The left-hand crystal shows the characteristic dome, y (041), in profile, as well as the cavernous effect of etching.

The color is generally colorless or slightly brownish; but a number are of a delicate aquamarine blue. The etching effects are so various and so complex that without careful study and drawings no idea of it can be conveyed. One feature, however, is universal and, as far as my experience goes, quite new for topaz. The faces of the brachypinacoid are always developed by the solvent as bright plane faces, visible in steps over the whole surface of the crystal and marked by beautifully sharp hopper-shaped depressions bounded by faces in the prism and brachydome zones. It is, therefore, always possible to orientate the most shapeless fragment even in the absence of the cleavage. It is noteworthy that but one crystal of the hundreds recovered was broken or in any way showed cleavage faces.

At the surface the topaz was generally pale blue, the crystals small and wedge-shaped, or so etched as to be but a mass of points and pits, and was embedded in lithia mica. Not a single crystal was found attached to the roof of the large cavity nor on its walls above the mud filling. But crystals were found in the mud at all levels, the largest ones, as already stated, near the bottom in lense-shaped albite cells. Small crystals were also found embedded in albite; in sericite probably derived from albite; and quite loose in the clay mass. Some of them have a thin coating of closely adherent sericite which scales off in sections showing an accurate mold of all the surface features of the topaz.

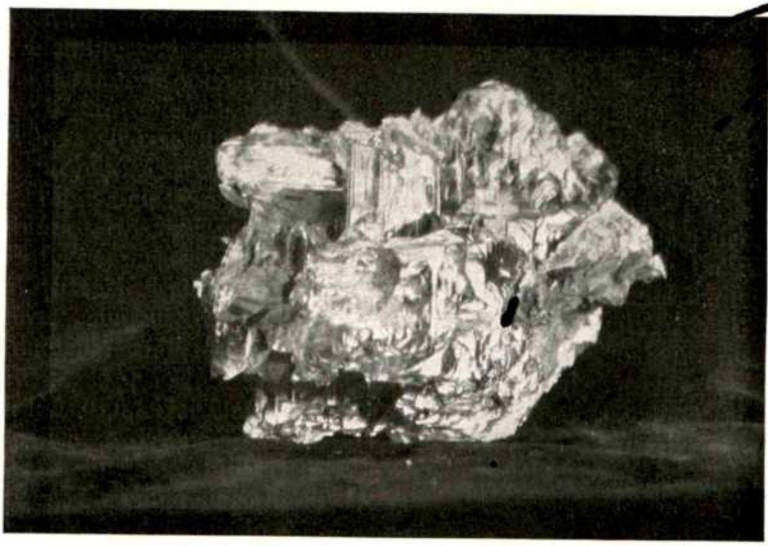

Fig. 3. Topaz crystal, Topsham. View from the direction of the *b* axis. Size 4½ by 6 inches. Shows the hopper-shaped depressions on the brachypinacoid resulting from etching.

Flattened needles of tourmaline are embedded in this sericite but do not penetrate the topaz. The only minerals enclosed in the topaz are an occasional idiomorphic quartz crystal and, in very rare cases, minute octahedrons of green zinc-spinel. Sericite, and rarely quartz and herderite, are implanted upon etched topaz surfaces. Generally, however, the topaz was quite free from any attached material and was at once noticeable on the screen when the mud was washed out by the higher luster and shining quality of its curved etch-faces.

Beryl:—Near the pocket at the surface and generally through the pegmatite, beryl is present in the ordinary aquamarine form. The crystals are more or less disintegrated but show normal habit. In the pocket material proper only two small fragments of blue beryl were found. Not until the very bottom of the mud layer was reached was beryl found in quantity. Here against the wall in a narrow vein several pounds of colorless or pale rose beryl was found. It was in fragments dissected by solution, the largest over a pound in weight. Three crystals only were recovered; these, strangely enough, had basal planes brilliant and perfect; the prism faces were plane but pitted with etch figures; and faces of two pyramids could be identified.

Gahnite:—The zinc-spinel, gahnite, had a singularly long period of deposition in this pegmatite. In another part of the Fisher Quarry a single rounded mass of this material weighing upwards of fifteen pounds had been taken from the graphic granite, where it was accompanied by garnets of equally large size. Fragments of this mass appear quite black, but on flaws and thin edges the deep green color is apparent. In sinking the pit about the pocket a number of octahedral crystals of this material were found embedded solidly in the graphic granite. A zone of yellow altered material about some of these, probably sericite, will be the subject of chemical investigation. In the pocket, gahnite is associated with albite. In the lower portions nearly every block of albite that was broken showed a band of scattered minute crystals of emerald green gahnite about half an inch beneath the free surface of the block. They must have been deposited simultaneously for a very short time while the albite was still growing and when this zone was the surface zone. In vugs of the albite, octahedrons or flat distorted hexagonal plates of gahnite reach a maximum dimension of one inch. The total amount of the material is, however, very small.

Tourmaline:—The mode of occurrence of the tourmaline has already been sufficiently described. It is universally acicular, the free ends of the crystals beautifully terminated by scalenohedral faces. The color is blue with greenish blue at the tips. Most of the crystals are coated with a firmly adherent layer of sericite. The coating may wholly enclose the needle but more often covers only about half the prism faces of the crystal. The thickest crystal seen was about half an inch in diameter. By far the greater number are of knitting-needle thickness and two inches or less in length.

Herderite:—Herderite was very abundant in the small pockets near the surface. It is in very sharply formed crystals, attached to quartz, albite, lepidolite and rarely topaz. As it was the last mineral to form in the deposit, its faces are clean and fairly brilliant. The largest crystals reach a length of two inches, and these are of ideal orthorhombic symmetry and very simple in form, showing only the prism *m*(110) and the brachydome *v*(011). Externally there is no trace of the twinning which is said to universally conceal the monoclinic nature of this mineral. Smaller crystals are more complex and await crystallographic study. The mineral is either colorless, snow-white or in some cases brownish with a peculiar enamel-like surface.

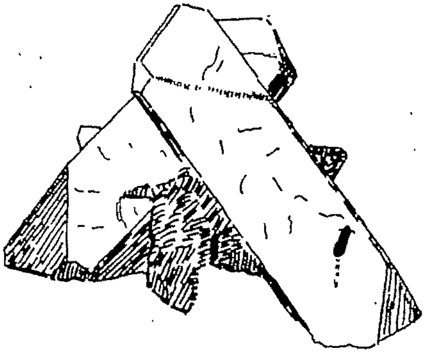

Fig. 4. Sketch of a group of herderite crystals, Topsham. Natural size; length of larger crystal about 2 inches.

Micas and Clay Minerals:—Frequent mention has been made of the micas, lepidolite and sericite, and of kaolin. The final determination and description of these minerals must await optical and chemical investigation. Their nature is evidently of great importance for an adequate understanding of the complex chemical history of this deposit.

Other Minerals:—There were found in small amounts the following minerals, which have as yet been but casually examined: columbite, zircon, apatite (a single crystal), torbernite, pyrite (?), and cassiterite.

Origin of the cavity:—There was evidence in the character of this cavity that it had been an empty space before the deposition of any of the minerals lining its walls and partially filling it. How it was formed is, of course, open to question. The presence of microcline fragments suggests the direct solution and almost total removal of original microcline of the pegmatite. After it had been formed, solutions rich in soda and lithia reached the cavity and began the building up of the layered albite, together with lepidolite intermingled with it, about the whole interior. A period of quartz deposition followed, to be succeeded in turn by the formation of beryl and topaz. Why these were confined to the bottom of the pocket and to the upper extremity of the pipe-like, vertical extension first found is inexplicable.

There followed a period of vigorous chemical activity, particularly evidenced in the lower half of the pocket. Blocks of microcline were coated with a dense layer of sericite or completely transformed to compact sericite. Albite surfaces were coated with the same material. Beneath this layer the feldspar was then either dissolved or kaolinized and lithia-tourmaline grew outward into the open or porous spaces so formed. Beryl and topaz were attacked by a solution indifferent to the quartz and albite surrounding them. Beryllium from the beryl and fluorine from the topaz united to produce herderite, but the source of the calcium and phosphoric acid requisite to produce this compound is unknown, unless it be assumed that apatite had been present and was completely destroyed. Only one crystal of apatite was actually observed in the pocket material. This seems to have marked the end of chemical activity since herderite is neither etched nor coated by other minerals.

Acknowledgments:—The author's indebtedness to Mr. Burbank who discovered the deposit and to Mr. Willes for permission to work it has already been recognized. Mr. Gonyer labored indefatigably for four weeks at the excavation, often without help, and his careful judgment in so measuring the charges of dynamite that the rock was broken without damaging the pocket minerals accounts in largest measure for the successful outcome of the exploration. Mr. Leonard H. Starbird, President of the Maine Mineralogical Society of Portland, assisted much in the hard work of moving rock and washing pocket mud. To Mr. Norman Smith of Brunswick

we are very grateful for the loan of air drill and compressor and men to run them, which greatly speeded up the work.

The drawing is by Mr. Burbank and the photographs reproduced were taken by Mr. Stroud, photographer of Brunswick, under the direction of Mr. Burbank.

If at any time other mineralogists have had the opportunity of working out such a complex mineral deposit with entire freedom to examine it from start to finish and to study its structure in detail, the record of their observations is unknown to the writer. He hopes that all those who helped the work will feel that in thus contributing to a new field of scientific observation they will find some measure of satisfaction.

Harvard University,
Cambridge, Massachusetts.

LATE PALEOZOIC AND EARLY MESOZOIC CHAROPHYTA.

RAYMOND E. PECK.

The Charophyta are a group of small plants of doubtful systematic position, ranked by some investigators as a class of the Thallophyta and by others as a separate phylum. They are widely distributed in clear fresh water and a few have been noted in the Baltic Sea,[1] a marine body of water with an unusually low mineral content. The group is rather inconspicuous and being of no economic value has attracted very little attention except among botanists. It is, however, of interest to geologists in that some species secrete calcium carbonate and are large contributors to fresh water limestones. It has been shown by Reid and Groves[2] that the fossil remains can be of great value in correlating fresh water deposits, and my investigations indicate that they can be of aid in correlating rocks as old as the Devonian.

Although many of the living charophyte plants are completely encrusted by calcium carbonate it is seldom that any recognizable organic structures are preserved except the spiralled oogonia. This is especially true in rocks older than the Cenozoic. On the death of the plant, the encrustation usually breaks down into a fine-grained calcareous mud.

Fossil charophyte oogonia consist of the calcium carbonate that was deposited on the interior of the spiral enveloping cells. On the living plants this deposition starts on the concave inner walls of the enveloping cells adjoining the oosphere and may replace almost the entire cell substance. In different stages of calcification the exterior of the "lime-shell" varies greatly in appearance. If only a thin deposit is made the oogonium will possess very sharp spiral ridges (see figure 7) with wide, deep concavities, the ridges representing the lateral union of the cells and the concavities the cells. If deposition continued, the cells of the fossil oogonium may be represented by broad spiral ridges (see figure 12) and the lateral union of the cells by narrow furrows. Any stage between the "concave cells" and the "convex cells" may occur in the same

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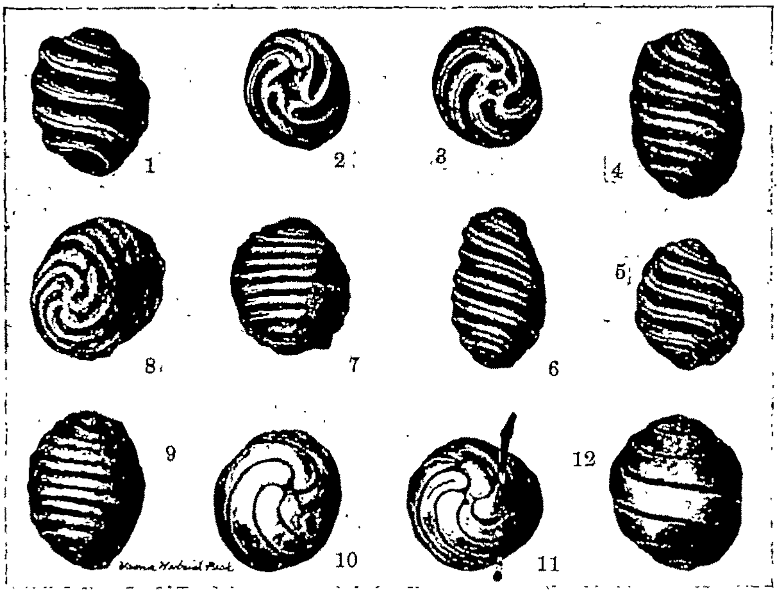
[1] Groves, James, and Bullock-Webster, G. R., British Charophyta: Ray Society, London, 1, page 6, 1920.

[2] Reid, Clement, and Groves, James, The Charophyta of the Lower Headon Beds of Hordle Cliffs: Quart. Jour. Geol. Soc., London, 77, pp. 175-192, 1921.

AM. JOUR. SC.—FIFTH SERIES, VOL. XXVII, NO. 157, JANUARY, 1934.

species and, in rare cases, on the same oogonium. The oogonia of all living Charophytes have five sinistrally spiralled enveloping cells, and the majority of fossil oogonia have five sinistrally spiralled ridges. These five spiralled oogonia are locally abundant in the Cenozoic, occur sparingly in the Cretaceous of Europe and North America, and have been noted in the Jurassic of Europe.[3]



EXPLANATION OF PLATE.

All specimens x 54.

Figs. 1-3, 5, 6. Gyrogonites moreyi, n. sp.
Figs. 1-3. Lateral, summit, and basal views of the holotype.
Figs. 5, 6. Lateral views of paratypes showing variations in shape.
Fig. 4. Gyrogonites sp.
Figs. 7-9. Gyrogonites glyptus, n. sp. (cotypes).
Fig. 7. Lateral view of a crushed oogonium.
Fig. 8. Basal view of a crushed oogonium.
Fig. 9. Lateral view of an oogonium of normal shape.
Figs. 10-12. Gyrogonites robertsi, n. sp.; basal, summit, and lateral views of the holotype.

The only undisputed record of sinistrally spiralled charophyte oogonia older than Jurassic, except those here reported, is that of *Palaeochara acadica* Bell,[4] a six spiralled species from the Carboniferous of Nova Scotia. However, dextrally spiralled oogonia, thought to represent another family of the Charophyta, are locally abundant in the Devonian and lower Mississippian.

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[3] Groves, James, and Bullock-Webster, G. R., British Charophyta: Ray Society, London, 2, page 78, 1924.

In 1856, Pander[5] noted the occurrence of two groups of small organisms from the Devonian of Russia under the name Trochilisken. One group closely resembles the charophyte oogonia in appearance but possesses from seven to ten spirals ascending dextrally. The other group, closely associated with the spiral forms, has from sixteen to twenty vertical units. These forms have since been noted at various localities and horizons within the Devonian and lower Mississippian of Europe, North America, and Africa, and have been described under the generic names *Calcisphaera* Williamson, *Moellerina* Ulrich, *Sycidium* G. Sandberger, and *Trochiliscus* A. Karpinsky. They have been classified as lycopod spores, phyllopod eggs, fish eggs, echinoids, foraminifera, and charophytes. Karpinsky,[6] in an excellent monograph on the European forms, discussed their systematic relationships and gave considerable evidence pointing to their charophyte affinities. I have been fortunate in having recently had the opportunity of studying a large number of exceptionally well preserved specimens from the Devonian and lower Mississippian of North America. The results of this investigation, giving new evidences indicating the relationship of these problematic forms with the Charophyta, appears in another journal.[7] In that paper I have introduced a tentative classification to include the living and fossil Charophyta. The group is divided into three families. One family, the Sycidiaceae, has a large number of vertical units and is evidently most nearly representative of the ancestral charophytes. The Trochiliscaceae, always with a lesser number of units than the Sycidiaceae, are oogonia with a dextral spiral. The third family, the Characeae, possess sinistrally spiralled oogonia, and includes the living charophytes as well as a large number of fossil forms. The Charophyta must have originated as a well defined group before the Devonian for in the lower Devonian the families Sycidiaceae and Trochiliscaceae are well represented. The fossil record depends on, first, when the group acquired the ability to secrete calcium carbonate, and second, when it became extinct. Many living species of charophytes do not secrete calcium carbonate and are not known as fossils. As our records now indicate, two families acquired the ability to secrete calcium carbonate in the Devonian and became extinct in the lower Mississippian.

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[4] Bell, W. A., A New Genus of Characeae and New Merostomata from the Coal Measures of Nova Scotia: Roy. Soc. Canada, Proc. and Trans., 3d ser., **16**, pp. 159-168, 1922.

[5] Pander, Christian H., Monographie der fossilen Fische des Silurischen Systems des russischbaltischen Gouv., p. 17, 1856.

[6] Karpinsky, A., Die Trochilisken: Memoires Du Comite Geologique, Nouvelle serie, Livraison 27, pp. 1-165, 1906. (Russian and German.)

[7] Jour. Pal. (in press).

Considering this ancient record it is surprising that the Characeae have not, with the exception of the single occurrence of *Palaeochara acadica* Bell, been noted below the Jurassic. Through the kindness of Dr. E. B. Branson and several students engaged in micropaleontology at the University of Missouri I have greatly extended the record of five celled, sinistrally spiralled oögonia by specimens from the Pennsylvanian, Permian, and Triassic? periods. I am indebted to Dr. E. B. Branson for valuable suggestions and criticisms offered during the preparation of this manuscript, and for his short discussion on the age of the upper Chugwater formation.

The classification of the living Charophyta is based largely on the non-calcified coronula cells and other details of the soft anatomy of the plants. For that reason it is difficult in most cases to give fossil oogonia the proper generic assignment. It has long been the custom of paleobotanists to refer most fossil oogonia with five sinistral spirals to the genus *Chara*. In 1927, Pia[8] pointed out that it is extremely unlikely that all oogonia grouped under the genus *Chara* could belong to it and that it might be better to refer fossil oogonia of doubtful affinities but with five sinistral spirals to the generic name under which they were first described, *Gyrogonites* Lamarck. Although this leaves the genus *Gyrogonites* without restrictions and more or less of a group name, in the present state of our knowledge it seems to be the best method available.

FAMILY CHARACEAE.

GENUS GYROGONITES LAMARCK.

Gyrogonites glyptus, n. sp.

(Plate 1, figures 7-9.)

Oogonium subspherical, small, ranging from .3 to .4 mm. in height, higher than wide, with greatest transverse diameter slightly above mid-height. Spiral ridges intercellular, narrow, closely spaced, and making approximately two complete turns. Ten ridges visible in a lateral view.

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[8] Pia, Julius, Hirmer's Handbuch der Paläobotanik, Band 1, p. 88, 1927.

Occurrence.—Algae Bed of the Chugwater formation near Lander, Wyoming. Dr. E. B. Branson (personal correspondence) has given his opinion on the age of this horizon as follows:

"Along the east flank of the Wind River Mountains in Wyoming the Chugwater group of the Triassic is 1400 to 1600 feet thick. It is largely of red fine-grained sandstone, but gypsum makes up more than 100 feet of it in many places. It may conveniently be divided into the members listed below:

Upper Chugwater. Fine grained red sandstone, gypsum beds, and thin limestone members, about 600 feet.
Popo Agie beds. Continental and near shore sandstones, shales, and conglomerates, 30 to 100 feet.
Middle Chugwater. Fine grained red sandstone, about 200 feet.
Alcova limestone. Dense dolomitic limestone, 1 to 20 feet.
Lower Chugwater. Fine grained red sandstone, about 600 feet.

"One of the thin limestone members about 30 feet from the top of the upper Chugwater contains many plant remains, probably algae, and the Charophyta described by Dr. Peck. The age of upper Chugwater has generally been considered as upper Triassic but recently it has been referred to the Sundance formation (Jurassic) by some writers.[9] However, the evidence for its Triassic age is strong and for Jurassic age weak.

There is an important unconformity between the upper Chugwater and the Sundance.
It contains no Jurassic fossils, definitely identifiable as such, and animals should have come in with an advancing sea.
The presence of a few fossils representing aberrant types that lived under unfavorable conditions represent a continuation of Chugwater conditions.
The presence of extensive gypsum deposits and of widespread thin limestone members formed as chemical precipitates indicate continuation of Chugwater conditions. Advancing seas are unfavorable for chemical precipitates of either lime or gypsum."

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[9] Reeside, J. B., Journal of Geology, 37, p. 50, 1929.
Bartram, John G., Journal of Geology, 38, p. 341, 1930.

Gyrogonites moreyi, n. sp.

(Plate 1, figures 1-3, 5, 6.)

Oogonium subovate to ovate-rotundate, ranging from .3 to .4 mm. in height, higher than wide, greatest transverse diameter at or usually below mid-height. Spiral ridges intercellular, fairly broad, making a little more than one complete turn around the oogonium. At the center of each ridge is a fine furrow marking the lateral contact of the cells. The furrows separating the ridges are approximately equal to the ridges in width.

Occurrence.—Cherokee (Pennsylvanian) shale about thirty-five feet above the Bevier coal at the Brick Plant, Columbia, Missouri; ?Winterset (Pennsylvanian) from Quarry at Swope Parkway and Prospect, Kansas City, Missouri; ?Waubaunsee (Pennsylvanian) near Manhattan, Kansas.

Holotypes and Paratypes.—Catalog numbers 31007-3, 31007-4, University of Missouri.

Approximately one hundred specimens of *G. moreyi* have been collected from the Cherokee by Mr. John Roberts and Mr. Philip Morey. They differ slightly in the length-width ratio, as is shown in the accompanying illustrations.

A single specimen has been collected from the Winterset limestone and another from the Waubaunsee formation. These forms are too poorly preserved to permit specific identifications and I am tentatively referring them to *G. moreyi.*

Gyrogonites robertsi, n. sp.

(Plate 1, figures 10-12.)

Oogonium globose, about .4 mm. in height, higher than wide, greatest transverse diameter slightly above mid-height. Spiral ridges cellular in position, broad, gently convex, making one complete turn around the oogonium. Narrow shallow furrows between the ridges mark the lateral contact of the cells.

Occurrence.—Cherokee (Pennsylvanian) shales about thirty-five feet above the Bevier coal at the Brick Plant, Columbia, Missouri.

Holotype.—Catalog number 31007-2, University of Missouri.

G. robertsi differs from all other recorded Pennsylvanian charophyte oogonia in having broad, gently convex ridges, the result of having the enveloping cells almost filled with calcium carbonate. It also differs from *G. moreyi* in shape and in the spirals making but one complete circuit.

The single specimen, the holotype, was collected by Mr. John Roberts. It was taken from the same sample that yielded a considerable number of *G. moreyi*, and a variety of ostracods, conodonts, and fusilinids.

Gyrogonites sp.

(Plate 1, figure 4.)

A single oogonium was collected from the Council Grove shale west of Manhattan, Kansas, by Mr. H. G. Walter. Although there is considerable doubt as to the Pennsylvanian-Permian contact in this area, the line is drawn at the base of the Council Grove on the United States Geological Survey correlation chart for Oklahoma and by most investigators. A brief discussion on this question is given by Condra and Upp.[10] The specimen is too poorly preserved to allow specific identification but I am noting it because of its importance as the first charophyte record from the Permian.

Figured Specimen.—Catalog number 31007-1, University of Missouri.

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[10] Condra, G. E., and Upp, J. E., Correlation of the Big Blue Series in Nebraska: Nebraska Geol. Surv. Bull. 6, 2d ser., p. 14, 1931.

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COLUMBIA, MISSOURI.

PRESENT STATUS OF THE FERNIE SHALE, ALBERTA.

P. S. WARREN.

CONTENTS.

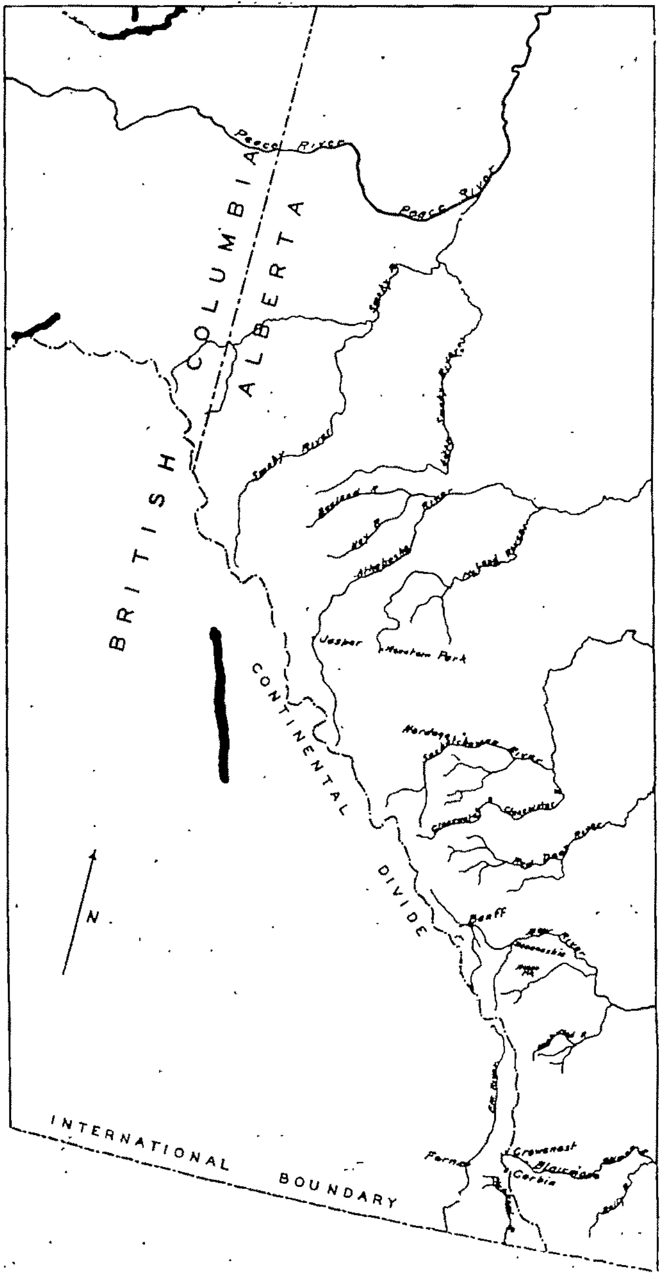
- Introduction.
- Historical.
- Lithology, distribution and thickness.
- Character of the boundaries.
- Faunal horizons.

INTRODUCTION.

The Fernie shale is a Jurassic formation occurring in the Canadian Rockies. The formation, or beds of similar age, extends from the vicinity of the 49th parallel to at least as far as the northern boundary of British Columbia. It lies, for the most part, on the Lower Triassic Spray River formation but toward the north, on the Upper Triassic Schooler Creek formation. It is overlain by the Lower Cretaceous Kootenay sandstone, or beds of similar age into which the Fernie seems to pass in most places by a gradational series of beds. Though the Fernie shale has been known for many years, it has never been subjected to a thorough stratigraphic study. Local occurrences have, from time to time, received careful treatment and fossils from various localities have been studied and described. The results of these investigations are scattered throughout geological literature. It seems desirable at the present time to sum up these results so that the geological importance of the Fernie shale may be better understood and appreciated by geological investigators and readers.

HISTORICAL.

The name "Fernie shale" was apparently first used by Leach[15] in describing the rocks of the Blairmore-Frank Coal-fields. Leach mentions the thinning of the Cretaceous beds to the east, which thinning is "particularly noticeable in the case of the lower dark shales which here represent the 'Fernie shales' of the Crowsnest field." Leach had studied the Crowsnest field the previous summer[14] where he had followed McEvoy who had left the services of the Geological Survey for employment in a private company operating in that area. It is quite probable that McEvoy and Leach had used the



Sketch map of western Alberta and eastern British Columbia showing localities mentioned in this paper.

term "Fernie shales" in their conversations on the geology of the coal fields and the word thus crept into literature without proper definition. The earlier workers in the foothills and mountains included the Fernie with the overlying Cretaceous coal-bearing beds known as the Kootenay formation. McConnell[21] and McEvoy[22] noted the black shales at the base of the coal-bearing beds but did not differentiate them as a distinct formation. Since Leach designated these beds the Fernie shales, the formation has always been separated from the overlying Kootenay. The determination by Whiteaves[38] of one of the ammonites collected by McEvoy from the formation at Fernie as *Cardioceras* and therefore of Jurassic age, undoubtedly aided in establishing the formation as distinct from the Kootenay. On the other hand, the fossils obtained by McConnell[21] from the Fernie shale near Devil's (Minnewanka) lake in the vicinity of the Cascade coal basin were considered by Whiteaves[38] to be Cretaceous. This led to considerable confusion that was not clarified till quite recent years. As most geologists who have had an opportunity of examining the Mesozoic sections in the mountains were more interested in the economic aspects of the coal-bearing beds than the purely stratigraphic problems presented by the underlying shale, the study of the Fernie formation progressed slowly.

Among the later workers whose investigations have contributed to a proper understanding of the stratigraphy and palaeontology of the Fernie shale, F. H. McLearn[28–31] of the Canadian Geological Survey stands preëminent. His study of the ammonites has led to a proper appreciation of the faunal zones present in the formation. In this work he was assisted by the late S. S. Buckman[8] of England. C. C. Crickmay[6], whose work on the Jurassic has been of a broader scope, has also contributed toward an understanding of the stratigraphic problems. Lastly, the writer[35–37] has been enabled, through the opportunities of examining many sections, to study some of the faunas and to suggest certain correlations.

LITHOLOGY, DISTRIBUTION AND THICKNESS.

It is easier to discuss the distribution of the Fernie shale in conjunction with a description of its lithological characteristics as such characteristics are apt to vary from place to place but never sufficiently to leave any doubt as to the identity of the formation. Such variations that occur in the lithology are probably overemphasized due to the fact that the whole formation can rarely be observed in any one section. The change in lithology may be largely stratigraphic so with different parts of the formation exposed in different localities the impression is given of considerable areal variation.

The formation is comprised of a series of shales usually dark in colour, commonly sandy, in places calcareous and occasionally slightly bituminous. Clay-ironstone or calcareous nodules are common in many localities though entirely lacking in others. The sandy shales are generally platy whereas the more argillaceous type are more fissile and darker in colour. The calcareous shales weather to a light grey colour and assume a fine platy character especially when dry. Some sections show the three types of shale and this is especially true in the southern extension of the formation. Toward the north the formation becomes more sandy even to the inclusion of many thin sandstone beds and the calcareous type of shales disappear.

An excellent horizon marker which is usually present in the Fernie is a bed of calcareous sandstone which occurs from 50 to 150 feet above the base of the formation. It varies in thickness from 5 to 30 feet, the thicker sections being more arenaceous and the thinner sections more calcareous. In some places the top of the bed is more calcareous than the base. The bed seems to thicken toward the east but this may not hold true for the whole extent of the formation. It also seems to thicken toward the north as the thickest sections of the bed have been measured in the northern area. It is proposed to name this bed the Rock Creek member of the Fernie, from Rock creek near Blairmore where the bed is well exposed.

Another member of the Fernie which appears to be present in most sections is a phosphate bed which occurs at the base of the formation. It attains a thickness of four to five feet in some localities. This bed is very persistent in the south where it has been thoroughly prospected. It appears to be lacking as a definite unit in some sections farther north. This is probably due to a change in character of the lower part of the Fernie through the introduction of a bed of black chert with interbedded shaly layers at the base of the formation. The chert bed is especially well developed in the Cadomin area. It is generally known as the black chert member of the Fernie.

The thickness of the Fernie varies considerably from place to place. In most sections a thickness of at least 800 feet can be measured. Sections of 2,800 feet and over have been reported but it is probable that duplication of beds has been responsible for some of this thickness. The difficulties of measuring a complete section are greatly enhanced by the incompetent character of the formation. The beds have everywhere been disturbed by folding and thrusting due to orogenic movements and duplication, and faulting has taken place without being discernible even to a careful observer. If we consider also that the shales are easily eroded and generally occupy valleys between the mountain ranges where they are mostly covered by detritus, it is easy to account for the discrepancy in the thickness as reported for various sections. It is believed, however, that the total thickness of the formation does vary considerably in different localities. This variation will be mentioned later in discussing the different sections.

The type section of the Fernie formation must be considered to be in the neighbourhood of the town of Fernie, B. C., from which the formation received its name. McEvoy[22] states that the formation here is 3,000 feet thick and reports the finding of an ammonite which Whiteaves later described as *Cardioceras* and on which the age of the formation was based. From the writer's experience, however, it seems very improbable that any reasonable section of the Fernie can be measured in this locality on account of the disturbed condition of the beds. Good sections, however, are exposed about 15 miles to the east of Fernie in the mountains west of the coal mine at Corbin. The following section was measured there on Leach creek by Mr. L. Telfer of the Consolidated Mining and Smelting Co. of Canada:

Overlying Beds, Kootenay Sandstone.

132	feet—	Black shale.
510	"	Grey calcareous shale.
60	"	Black shale with some calcareous shale with nodules at base.
160	"	Black shale.
7	"	Calcareous sandstone (Belemnite bed) [Rock Creek member].
50	"	Black shale.
1.5	"	Grey limestone (bituminous).
4	"	Phosphate bed.
924.5		

Underlying Beds, Spray River Formation.

A similar section measured by the writer a few miles to the east of this locality gave a total thickness of about 800 feet. The difference in measurement between these two sections is considered to be largely due to repetition or squeezing out of beds. The section at the phosphate mine at Crowsnest is very similar lithologically and displays a measured thickness of 808 feet. In these three sections the strata is tilted but otherwise not greatly disturbed by faulting and folding and they are considered as typical sections of the Fernie in the type locality. On the other hand, MacKay[16] gives a section measured at Corbin, which is intermediate in position between the first two and the last mentioned sections, with a thickness of 2,800 feet. The strata in this locality, however, is notably broken and disturbed and the great thickness of MacKay's section must be attributed to repetition. Another section in Crowsnest pass which should be mentioned here is that studied by McLearn[29] near Blairmore on the south slope of Grassy mountain. MacKay[17] gives a measurement of 900 feet for this section which includes 50 feet of beds at the base which are doubtfully Jurassic. This section does not show the same amount of calcareous shale that is developed in the more westerly sections.

The typical sections in Crowsnest pass and vicinity, therefore, show the Fernie shale to be less than 1,000 feet thick with a considerable development of calcareous shale in the west which is absent for the most part in the eastern sections.

South of Crowsnest pass the Fernie has been studied by MacKenzie[18] in the Flathead River valley. It consists of evenly laminated, brownish and greyish shale which grades into the overlying Kootenay. He estimates a thickness of 1,000 feet for the formation but it is evident from MacKenzie's section that he included with the Fernie at least some of the underlying Triassic beds.

The extent of the Fernie south of the Flathead valley is not known. According to our present information it must pinch out rapidly in that direction as Daly[7] did not identify the formation when surveying the International boundary. It is just possible that at the boundary the formation was completely obscured by detritus and so overlooked by Daly. At the present time we have no data as to the connection of the Fernie with the Jurassic Ellis formation of Montana though it is known from palaeontological evidence that the Ellis and probably the upper part of the Fernie were deposited at the same time.

North of Blairmore a section of Fernie shale is exposed in Canyon creek at Moose mountain. Hume[18] gives the thickness as 205-220 feet, composed of dark brown to black shales with a highly bituminous appearance. A few calcareous layers are intercalated and the shales become sandy in the upper part. The Fernie here lies disconformably on the Mississippian Rundle limestone and is separated from the overlying Kootenay by an unconformity. In Turner valley, to the northeast of Moose mountain, the Fernie encountered in the deep wells has much the same thickness as at Moose mountain and contains a well defined glauconite horizon.

On the upper part of Sheep river and on Kananaskis river, the Fernie is thicker, ranging up to 1,000 feet. The Rock Creek member is well developed here and is highly fossiliferous in places. The calcareous shales are lacking and the formation seems to be more sandy than in the southern exposures. The formation overlies the Spray River formation and appears to grade into the Kootenay above.

In Cascade valley[8] near Banff, the Fernie shale is well exposed near the west end of Lake Minnewanka. It is about 1,600 feet thick, consisting of dark, rather sandy shales with occasional intercalated sandy or calcareous beds. These beds increase in importance toward the top where the formation grades into the overlying Kootenay. The Spray River formation is well developed below the Fernie. The formation is also exposed three miles north of the east end of Lake Minnewanka where McConnell[21] collected the Sonninian fauna and where, later, Crickmay[6] collected a Stephanoceras fauna in close proximity. There is no data regarding the formation at this point but the collections were probably made from the Rock Creek member.

Farther north the formation is known to be present on Red Deer river.[40] On North Saskatchewan river Malloch[20] found soft, calcareous shales, dark grey to nearly black in colour which he attributes to the Fernie. His section measured 722.5 feet though he speaks of a section 2,900 feet thick between Red Deer and Clearwater rivers. He mentions the difficulty of separating the Fernie from the overlying Kootenay. To the east of Malloch's area, at Nordegg, Allan and Rutherford[1] give the thickness of the Fernie as 250-300 feet, the upper part of which is predominantly sandstone. In this section the Fernie was considered to carry up to the Kootenay conglomerate. The basal bed is black chert intermixed with shale.

In the Mountain Park area northwest of Nordegg the formation is well exposed and a section of over 1,500 feet of strata may be observed through intermittent exposures. At the base of the formation the black chert member is developed to a thickness of over 20 feet. It contains poorly preserved pelecypods and belemnites. The Rock Creek member is present about 150 feet above the base and develops a thickness of at least 30 feet. The shales above this member are dark grey to black, and arenaceous in character. They grade up into the Kootenay (locally known as the Nikanassin formation). The Fernie overlies the Spray River formation, the upper beds of which are white limestones. The true thickness of the Fernie cannot be accurately obtained in this section on account of faulting and folding.

In the outer ranges in Jasper Park along Athabaska river the Fernie outcrops in several sections, none of which expose the complete formation. The lithology of the formation seems to be similar to that of the Mountain Park area except that the black chert member at the base is not so well developed. Arenaceous beds become more prominent toward the foothills to the east. The Fernie in this region has not been subjected to a thorough stratigraphic study.

North of Athabaska river the formation has been recognized on Smoky, Hay and Berland rivers.[19] On Peace river a shale of similar lithological character and stratigraphic position overlies the Upper Triassic Schooler Creek formation and underlies the continental Lower Cretaceous beds. These have been named the Pine River formation by Spieker[34] who obtained fossils including *Pinna, Pecten* and *Lima* which are apparently not definitely diagnostic. There seems little doubt, however, that lithologically and stratigraphically, the Pine River formation is the northern continuation of the Fernie shale.

Although fossils of presumably Jurassic age have been obtained north of the Peace, geological data as to their containing beds are largely lacking. It seems preferable at the present time to postpone any discussion of the Fernie shale in its northern extension till more definite information can be obtained.

CHARACTER OF THE BOUNDARIES.

The lower boundary of the Fernie is unconformable in any section so far studied. The Fernie usually overlies the Lower Triassic Spray River formation and there seems to be no discordancy in dip between the formations. The lithological change, however, between the Fernie and Spray river is quite marked. The lowermost bed of the Fernie is, in most sections, strongly phosphatic and provides a good horizon marker except for the fact that it is usually covered with detritus. In the Peace river section, the Pine River shales, which are believed to be the equivalent of the Fernie, lie on the Upper Triassic Schooler Creek formation. The relationships of the two formations are not well known.

In one section only do we find the Fernie overlapping on older formations. This is at Moose mountain where the Fernie directly overlies the Rundle limestone of Mississippian age. Apparently the upper part of the Rundle, the Rocky Mountain quartzite (Pennsylvanian) and Spray River formation are missing in this section. Moose mountain is in the foothills to the east of the front range. It is known from other sections that the Rocky Mountain quartzite and Spray River formation thin rapidly to the east and locally disappear before reaching the front range so the relationships of the Fernie and the Rundle as shown on Moose mountain probably hold for most of the foothills area.

The upper boundary of the Fernie provides an interesting problem. In most sections the shale grades upwards by the intercalation of sandstone beds into the overlying Kootenay formation. The highest fauna so far obtained from the Fernie represents Argovian of the middle Upper Jurassic and the fauna of the Kootenay has always been quoted as of Barremian age of the Lower Cretaceous. There seems, therefore, to be a distinct hiatus, so far as the faunas and floras are concerned, between the two formations, the uppermost Jurassic and the lowermost Cretaceous not being represented. The logical conclusion to be drawn is that there is a stratigraphic break between the formations which is not readily discernible by careful observation in the field. On the other hand, further study of the formations may bring to light an older flora in the Kootenay or a younger fauna in the Fernie. It would appear, however, that there is an insufficient thickness of strata to represent the time equivalent of the floras and faunas that are missing.

A disconformity between the Fernie and the Kootenay has been reported from only one locality. This is at the Moose mountain section. The Fernie here is very thin, only 205-220 feet and as Lower Jurassic and lowermost Middle Jurassic fossils have been reported from this locality,[18] it is evident that all the upper part of the Fernie was eroded before Kootenay time thus accounting for the discrepancy in the thickness of the formation in this section. It does not appear reasonable to assume, however, that this disconformity is present in those sections where the Fernie is represented by its normal thickness. On the other hand, it tends to demonstrate that, in the area underlying the foothills of Southern Alberta or as far east as the Fernie and Kootenay extend, the two formations are unconformably associated.

FAUNAL HORIZONS.

The first contribution to our knowledge of the age of the Fernie shale was the identification and description by Whiteaves[39] of a species of *Cardioceras* collected by McEvoy[22] near Fernie, B. C. This data was further augmented by the discovery on Red Deer river of an ammonite described as *Peltoceras* by Whiteaves.[40] These two genera represent two closely related horizons in the Upper Jurassic and Whiteaves, with this information on hand, quite rightly correlated the Fernie with the Jurassic deposits of the Black hills, etc. As nothing further was known of the fauna of the Fernie for many years, it was generally considered that the Fernie shale was deposited in a northern extension of Logan's sea and corresponded in age to the Ellis and Sundance formations of the western United States. Later findings proved this assumption to be incorrect in as much as, though the Ellis-Sundance horizon has been proved to be present in the Fernie shale at certain localities, most of the formation is older than any horizon so far discovered in the deposits of Logan's sea. Information concerning the earlier age of part of the Fernie shale was produced by McConnell[21] in an early reconnaissance. This was the finding of a Sonninian fauna in the Fernie shale at Lake Minnewanka (Devil's lake) near Banff. This information was unfortunately misinterpreted by Whiteaves[38] and it was not till more recent years that the earlier faunas of the Fernie were discovered and properly determined. Faunas ranging from Lower Lias to middle Upper Jurassic are now known to exist in the formation.

The earliest fauna so far discovered in the Fernie shale is the Sinemurian (Lower Jurassic) fauna from the Fernie area, B. C.[36] This was obtained from several localities at the very base of the formation by Mr. L. Telfer and consists of poorly preserved pelecypods and ammonites. The ammonites were ascribed to the genus *Arniotites*. Better preserved material shows that the genus is probably *Eparnioceras*. The same genus has since been obtained from the base of the Fernie near Banff, and a fauna of probably similar age, as yet undescribed, occurs in one locality in the Jasper area. As these faunas have all been obtained from the very base of the formation it is reasonable to assume that no earlier faunas occur in the Fernie shale.

Poorly preserved specimens with Liassic affinities have been collected from some localities. Ammonites from the Fernie district obtained by Mr. Telfer from above the *Eparnioceras* zone show distinct affiliations with "*Grammoceras*." The suture line is not preserved. Another ammonite collected by Allan and Rutherford in the Jasper area near the base of the formation is undoubtedly a Dactylioceratid. Hume also reports a Dactylioceratid-like ammonite from near the base of the formation at Moose mountain. These are both Upper Lias types. Collet[5] also obtained Upper Liassic ammonites in the Jasper area which he identified as *Hammatoceras insigne* Schubler and *Dumortieria* or *Catulloceras* and which he regards are Upper Toarcian in age. These finds are significant in that they demonstrate the presence of several definite Liassic horizons in the Fernie shale and the probability that most of Lower Jurassic time is represented in the lower part of the formation.

Bajocian (lower Middle Jurassic) faunas are probably the best known at the present time in the Fernie. The earliest one is that found by McConnell near the north end of Lake Minnewanka where ammonites representing the genus Sonninia are present together with brachiopods and pelecypods. This fauna, originally ascribed to the Cretaceous by Whiteaves was properly placed at a later date by McLearn.[27] The ammonites have not as yet been fully studied. The molluscs represent a very definite group including *Ostrea, Plagiostoma, Oxytoma, Trigonia, Astarte, Protocardia, Pleuromya,* etc. This fauna has not been found elsewhere. At a slightly higher horizon and in the Rock Creek member of the formation a more widespread and very prolific fauna occurs[87] including such ammonites as *Teloceras, Stemmatoceras, Defonticeras, Saxitoniceras* and *Zemistephanus* together with a variety of other forms including *Belemnites, Rhynchonella, Cucullaea, Inoceramus, Oxytoma, Cardinia, Trigonia, Camptonectes, Entolium, Plagiostoma, Pleuromya, Thracia, Arctica, Protocardia,* and *Pleurotomaria.* This fauna has now been obtained in practically every locality examined from Crowsnest pass to Jasper park.

Crickmay reports it to be present at McConnell's locality at Lake Minnewanka closely associated with the Sonninian fauna.[6] The pelecypods of the two faunas appear to be very closely related. This *Teloceras* fauna will probably prove the best horizon marker in the Fernie shale on account of the abundance of specimens which may usually be obtained when the horizon is found. Most of the other faunas are known from a very few specimens especially those of the Lower Jurassic.

A fauna of somewhat similar age has been reported by McLearn[26] from calcareous sandstones at the top of the Rock Creek member on the south slope of Grassy mountain near Blairmore. This *Chlamys mcconnelli* fauna of McLearn consists of pelecypods including *Chlamys, Gryphaea, Alectryonia, Camptonectes, Lima* and *Plagiostoma.* There are no ammonites present but the position of the fauna in the Rock Creek member shows its close association with the *Teloceras* fauna even though the pelecypods are quite distinct from those of other faunas found at this horizon. McLearn designates the calcareous sandstones containing this fauna the Lille member.[27]

Approximately 450-595 feet above the Rock Creek member another assemblage of pelecypods appears together with some ammonites. This is McLearn's *Corbula munda* fauna.[29] Pelecypods are very abundant including such forms as *Cucullaea, Gervillia, Inoceramus, Oxytoma, Pseudomonotis, Ostrea, Gryphaea, Trigonia, Camptonectes, Entolium, Lima, Anomia, Modiolus, Pleuromya, Protocardia, Corbula,* etc. With these occur the ammonite genera *Miccocephalites, Metacephalites* and *Paracephalites.* Buckman, who described the ammonites,[2] gives a Proplanulitan age for this assemblage which is Callovian or early Upper Jurassic time. This fauna is abundant in the Blairmore region and the writer has found some elements of it in a section farther to the west. Some of the pelecypods show quite a striking resemblance to certain species in the *Teloceras* or Bajocian fauna below but no species appear to be common to the two faunas. That the horizon is present in localities farther north is shown by the discovery on Kananaskis river of a specimen of *Seymourites,*[28] an ammonite of Proplanulitan age but the Blairmore ammonites and pelecypods are apparently absent. It is apparent that this fauna may become a good horizon marker in the formation.

Two faunal horizons are known above the *Corbula munda or Miccocephalites* horizon, unfortunately both identified as yet by but a single species and specimen of ammonite. The first is that from which Dowling obtained his *Peltoceras occidentale* Whiteaves[40] on Red Deer river in Rocky Mountain park and which is undoubtedly younger than the *Corbula munda* fauna. This horizon has not been recognized elsewhere in North America. The second horizon is marked by *Cardioceras canadense* Whiteaves[39] found by McEvoy at Fernie and is Argovian in age. It has a widespread distribution in North America being one of the characteristic elements of the fauna of Logan's sea. It has not, however, been found elsewhere in the Fernie shale and its exact position in the formation is not known.

The *Cardioceras* fauna is the youngest so far obtained from the Fernie shale. Until the exact stratigraphic relationships of those fauna are known, it is impossible to predict if later faunas are to be expected. It is quite probable, however, that the *Cardioceras* fauna occurs in the very upper part of the formation as the "grit bed" in which it was found is probably one of the sandy beds in the transitional zone between the Fernie and the overlying Kootenay. This horizon has been examined by the writer in several localities without much success. The beds are remarkably barren of fossils though the strata appears to have been deposited under marine conditions, probably during the retreat of the Jurassic sea. A judgment based on these data as well as on our knowledge of the stratigraphy of the Logan's sea deposits in adjacent areas would preclude the possibility of the occurrence of any later faunas in the Fernie shale.

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Chemistry.

Allen's Commercial Organic Analysis; Vol. X. Pp. ix, 817. Fifth Edition. Philadelphia, 1933 (P. Blakiston's Son and Co., $7.50).—This volume marks the completion of the fifth edition of this monumental reference work. The field of organic analysis as covered in the Allen series is a most difficult one. It does not have to do with the identification and analysis of pure organic compounds to any extent, but for the most part includes extremely complex substances such as fats, essential oils, alkaloids, glucosides, and proteins. In this wide and varied field there are very few "standard methods." This lack necessitates the critical evaluation of methods published in the literature. This service has been rendered in this and the preceding volumes by a group of experts, each covering a highly specialized field. The final volume—which deals with haemoglobins, scleroproteins, structural proteins, methods of vitamin assay, hormones, pectins, and identification of woods—is up to the general standard of excellence which has always characterized this text. The final volume contains not only its own index but a complete index to the entire ten volumes.

W. T. READ.

Geology.

Summary of Progress of the Geological Survey of Great Britain and the Museum of Practical Geology for the year 1932. Part II. Pp. 142; 10 pls., 27 figs. London, 1933 (H. M. Stationery Office, price 3s. net, postage extra).—Six articles are included in this volume. Of special interest is the series of three papers on the Kent Coal Field. These are as follows: Sequence and Structure, by H. G. Denis, pp. 15-43, pls. II, IV; the Fossil Flora, by R. Crookall, pp. 44-70, pls. V-VII; the Fauna, by C. A. Stubblefield, pp. 71-77. Other papers are as follows: Composite auto-intrusion in a Carboniferous lava flow, by W. A. Kennedy, pp. 83-93, pl. VIII; Lower Ordovician Graptolite Faunas, by Gertrude L. Ellis, pp. 94-111, figs. 1-13; Fauna of the Little Missenden Boring, S. H. Straw and A. S. Woodward, pp. 112-141, pls. IX, X.

Publications of the United States Geological Survey; W. C. Mendenhall, Director.—Recent publications are noted in the following list. (See earlier, volume **25**, pp. 266, 267).[1]

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[1] These publications can be obtained as follows: 1. Maps from the Director of the Survey, usual price of each sheet 10 cents, a discount of 40 per cent on orders of $5.00 or more. 2. Reports at the prices given; 3. Guide Books, from the Superintendent of Documents, Government Printing Office, Washington, D. C. Remittance in each case by money order.

TOPOGRAPHIC ATLAS.—Fifty-eight sheets.

PROFESSIONAL PAPERS.—No. 175. Shorter contributions to General Geology. A. Miocene Foraminifera of the Coastal Plain of the Eastern United States; by JOSEPH A. CUSHMAN and EDGAR D. CAHILL. Pp. 1-50, pls. 1-13 (15 cents). Upwards of 100 species are described and figured. Their geographic distribution is given on a large insert sheet (16 x 27 inches).

B. Some of Alpheus Hyatt's unfigured types from the Jurassic of California; by C. H. CRICKMAY. Pp. 51-64, pls. 14-18 (5 cents).

C. Replacement origin of the albite granite near Sparta, Oregon; by James Gilluly. Pp. 65-81, pls. 19-23, figs. 1-2.

D. Origin of the Anhydrite Cap Rock of American Salt Domes; by MARCUS I. GOLDMAN. Pp. 83-114; pls. 24-42 (15 cents).—This paper suggests that the anhydrite cap rock of salt domes originated by the residual accumulation and consolidation, on top of a salt stock, of sedimentary anhydrite freed from salt by solution of the top of the stock. This view is supported by the presence between these layers of a flat solution surface, the "salt table," decapitating anhydrite-bearing folds in the salt.

BULLETINS.—No. 830. Contributions to Economic Geology. B. Geology of gold mines in southwestern Oregon; by P. J. SHENON. Notes on mines in Douglas Co., Oregon, by F. G. WELLS. Pp. 33-64, pls. 4-14, figs. 3, 4 (15 cents).

No. 831. 1931-32. Pt. II. Mineral Fuels. Title page and index.

No. 836. Mineral Resources of Alaska, 1930. D. Eastern portion of Mount McKinley National Park; by S. R. CAPPS; Kantishna district and Mining Development in the Tatlanika and Totatlanika Basins, by F. H. MOFFIT. Pp. 219-345, pls. 4-6 (maps), figs. 6-10 (35 cents).

No. 840. Geology and mineral resources of the Middletown quadrangle, Pennsylvania; by G. H. STOSE and A. I. JONAS. Pp. 86, 15 pls. (including 2 maps), 16 figs. (40 cents).

No. 841. Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah, by A. A. BAKER. Pp. 95, 11 pls. (including 2 maps), 3 figs. (50 cents).

No. 844. Mineral Resources of Alaska, 1931. A. Mineral industry of Alaska in 1931 and Administrative report, by P. S. SMITH. Pp. 117, 3 figs. Selected list of Geological Survey publications on Alaska follows, pp. 1a-15a (10 cents). B. Mineral investigations in the Alaska Railroad belt, 1931, by S. R. CAPPS. Pp. 119-135, pl. 1 (map) (5 cents).

No. 845. Guide Book of the Western United States. Part F. Southern Pacific Lines. New Orleans to Los Angeles, by N. H. DARTON. Pp. 304, 29 maps, 49 pls., 71 figs. ($1.00 paper cover).

No. 849. A. Surveys in the Anthracite Ridge District, Alaska; by R. W. RICHARDS and G. A. WARING. Pp. 27, 2 pls., 1 fig. (5 cents).

WATER SUPPLY PAPERS.—N. C. GROVER, Chief Engineer.—Nos. 710-725; prices 10, 15, 20 and 50 cents.—Basins as follows: No. 711, Atlantic Slope; 712, Pt. 2, So. Atlantic and East Gulf of Mexico; 713, Ohio R., Pt. 2; 714, St. Lawrence R., Pt. 4; 715, Hudson Bay and Upper Mississippi, Pt. 2; 716, Missouri R., Pt. 6; 717, Lower Mississippi R., Pt. 7; 718, West Gulf of Mexico. Pt. 8; 719, Colorado R., Pt. 9; 721, No. Pacific Slope, Calif., A. B. C., Pt. 11; 722, 723, 724, Pt. 12, No. Pacific Slope. Also Nos. 710, 725, Hawaii.

Circulars.—No. 1. Iron Ore in the Red Mt. Formation, Greasy Cove, Ala.; by E. F. Burchard. Pp. 46, 1 pl., 5 figs. No. 2. Copper Deposits in southwestern Oregon; by P. J. Shenon. Pp. 35, 6 pls., 5 figs. No. 3. The Bleaching Clays; by P. G. Nutting. Pp. 51, 11 figs. No. 4. Deposits of Ornamental Stone in Montana; by G. R. Mansfield. Pp. 22, 6 pls., 2 figs.

GEOLOGICAL GUIDE BOOKS.—These guide books were prepared for the excursions in connection with the 16th session of the International Geological Congress, which met in Washington July 22-29. They give a summary of the geology of a large part of the United States and are consequently of permanent value; also not too technical to be understood by one who has a foundation of general geologic knowledge.

Forty-nine are here included. The individual titles, with prices (10 to 35 cents), can be obtained from the Superintendent of Documents (see footnote 1).

Groundwater in the Paleozoic rocks of Northern Alabama; by W. D. JOHNSTON, Jr., with analyses by MARGARET D. FOSTER and C. S. HOWARD. Geol. Survey Alabama, Walter B. Jones, State Geologist. Special Report No. 16. Part I: Text, pp. xvi, 414; 23 pls., 54 figs. Part II, Well and Spring Tables, including map (12 x 14 in.).—After giving a geologic introduction of 134 pages, this report presents in detail the groundwater hydrology of the counties of northern Alabama. ADOLPH KNOPF.

On the Mineralogy of Sedimentary Rocks. A Series of Essays and a Bibliography; by P. G. H. BOSWELL. Pp. x, 393. London, 1933 (Thomas Murby & Co., 21s. net); New York, (D. Van Nostrand Co.)—This work is an important addition to the literature of sedimentary petrology. It consists of two very diverse parts. The first part, of 130 pages, comprises eleven chapters that set forth the history, scope, and aims of the petrology of the sedimentary rocks. Such important matters as the individuality of sediments, the stability of detrital minerals, the paleogeographic evidence afforded by sediments and stratigraphic correlation by means of the minerals contained in sedimentary rocks are among the topics covered. Despite some unfavorable comment on the worth of this part of the book, it is nevertheless highly valuable: it serves in a measure as an introduction to the second part, it shows clearly the present status of the field of research, it indicates the unsolved nature of many problems, and it suggests, or should suggest to the reader, profitable lines of investigation.

The second part of the book is a bibliography of more than 1025 entries carefully annotated, many of the annotations being in fact rather full digests. Six indexes (General, Stratigraphical, Horizons, Localities, Minerals, Figured Minerals, and Technique) make the vast mass of material assembled in the bibliography unusually easily available. ADOLPH KNOPF.

Foraminifera, their Classification and Economic Use. Second Edition; pp. 349, 31 pls., and text figs.; accompanied by *An Illustrated Key to the Genera of the Foraminifera,* pp. 24, 40 pls.; by JOSEPH A. CUSHMAN. Cushman Lab. Foram. Research, Special Publications 4 and 5, Sharon, Mass., 1933.—The first edition of this widely used handbook of fossil and living Foraminifera was noticed five years ago in this Journal. Not only has this second edition been improved and brought up to date, but the key to the families presented in the former book has now been amplified to include the genera and published as a separate volume, a method that makes for greater convenience in reading the generic descriptions and for greater clarity of understanding. The 45 families and 412 genera of the first edition have grown into 47 families with 532 valid genera and subgenera. The difficult families of the Fusulinidae and Orbitoididae, "two families of great importance, which need in each case, a specialist to fully understand their unique structures and rapidly increasing literature," are described by Carl O. Dunbar and T. Wayland Vaughan, respectively.

Doctor Cushman has the unique distinction of having studied the original material of nearly all the type species during his more than thirty years of work on the Foraminifera. He has been conservative and has kept out of this book (but not out of mind) the many inadequately described genera of pioneer authors, awaiting rediscovery of authentic material or restudy of the actual genotypes. A new chapter has been added on the vexed problem of trimorphism, and another dealing with research problems. By adopting a slightly smaller font of type, the descriptive matter has been compressed into fewer pages than in the first edition and the improved dress of the new edition is a matter for congratulation. The author of this very useful work deserves the thanks of all concerned with the important group of Foraminifera. C. S.

Glossary and Correlation Charts of North American Tertiary Mammal-bearing Formations; by GEORGE G. SIMPSON. Bull.

Amer. Mus. Nat. Hist., 67, Art. III, pp. 79-121, 1933.—This important work on correlation, with a glossary of the continental deposits of North America, should be on the desk of all stratigraphers, since it brings out the status of over 130 formations or mammal horizons. Of these names 45 are of little or no use. The remaining 90 units are located on a geographic map and 65 of them appear in the seven correlation charts.

The Mesozoic era is ended with the Lance and Hell Creek formations, and the first epoch in the Cenozoic is the Paleocene, which begins with the Puerco and closes with the Clark Fork. Above the Paleocene the guiding fossils are the horses, which are of major significance in bounding the mammal horizons. The article is a fine report of progress, and makes clear what is known, what is debatable, and what needs further field discoveries. The author is to be congratulated on this very helpful summary.

C. S.

A Manual of Foraminifera; by J. J. GALLOWAY. Pp. xii, 483; 42 pls. with numerous figs.; also a portrait as frontispiece. Bloomington, Indiana, 1933 (The Principia Press).—It is to be noted that this publication stands as No. 1 of the James Furman Kemp Memorial Series. Dr. Kemp, who died in 1926, was made professor of geology at Columbia University in 1891.

Physics of the Earth—VI: Seismology. Bulletin 90 of the National Research Council. Pp. 223; 28 figs. Washington, D. C., 1933 (Paper $2.00, cloth $2.50).—Numerous scientists who try to follow the rapid development of seismology will welcome this authoritative and up-to-date treatment of the subject. The book consists of twenty chapters, each written by a recognized authority; the authors are J. B. Macelwane, H. O. Wood, H. F. Reid, J. A. Anderson, and P. Byerly. Subjects discussed include: Causes of earthquakes, methods of field investigation, the several types of seismic waves, principle of the seismograph, analysis of earthquake records, and seismic geography. Some of these subjects require mathematical treatment, but in general the book is not highly technical; in fact, the avowed aim is "to enable scientific workers in other fields to acquaint themselves with some of the principal seismological problems, methods, and results." Each chapter has a useful list of references to other books and articles.

CHESTER R. LONGWELL.

BIOLOGY.

The Scientific Basis of Evolution; by THOMAS HUNT MORGAN. Pp. ix, 286; 42 figs. New York, 1932 (W. W. Norton and Co., $3.50).—The substantial evidence which recent discoveries in genetics have to offer toward a solution of the problem of evolution is here presented by the acknowledged leader in this field of experimental biology. Since the book is intended for the general reader a brief summary of the cellular mechanism of heredity serves as an introduction to the discussion of variability, adaptation, natural selection, sexual differentiation, embryonic development and the commonly assumed inheritance of acquired characteristics. Each of these topics, as well as the social evolution of man, stripped of assumptions and emotional settings, takes on a new significance when presented in the light of clearly reasoned evidence. The final chapters, on evolution as a response to the order of nature and on the mechanistic and metaphysical interpretations of biology and of evolution, answer some of the objections which have been raised against the physico-chemical explanation of life by the metaphysical conceptions of immaterial vital forces.

The book will compel many a scientist to reconsider the evidence on which he has based his biological conceptions, while it will give the general reader a lucid and reliable account of what is now known about a subject of universal interest. W. R. C.

Reptiles of the World; by RAYMOND L. DITMARS. New revised edition. Pp. xx, 321; 89 pls. New York, 1933 (Macmillan Co., $5.00).—The ways of life of the lizards, crocodilians, snakes and turtles are here revealed in a simple, interesting and untechnical style. The book is written by one who probably knows them more intimately than any other man of our time. In it one will find answers to most of the questions which may arise concerning hundreds of interesting creatures which are but little known to the general reader, with extraordinarily lifelike photographs of nearly two hundred species in characteristic attitudes.

Like the earlier editions the book will be a fruitful source of reliable information for the naturalist, while the reader with no previous knowledge of reptiles will be intrigued by the vivid portrayal of their activities both in captivity and in nature.

W. R. C.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Annual Report of the Board of Regents of the Smithsonian Institution; Dr. C. G. ABBOT, Secretary. Washington, 1933. Pp. xiii, 497; (70 cents, paper cover; from the Superintendent of Documents).—Of the many prominent events of the past year, noted in this volume, first to be mentioned is the unrestricted bequest of $100,000 to be added to the Endowment Fund. This is from the estate of the late Dwight W. Morrow.

The activity of the Institution in its many branches is fully presented. Thus, in the line of publication, 121 volumes and pamphlets have been issued: 50 from the Institution; 63 from the National Museum; and the others from the Bureau of American Ethnology and the Astrophysical Observatory. The total number of publications distributed was 223,045. To be mentioned also is the "Smithsonian Scientific Series"; this consists of 12 volumes on a variety of interesting subjects; they are popular in style and well illustrated.

The Expeditions have also been actively carried forward. As an example of the results obtained, it may be mentioned that British Guiana yielded 317 live animals for the National Zoological Park. The Astrophysical Observatory published Volume V of the Annals giving the results of solar researches in the past 10 years. This is the department to which Dr. Abbot has through the years made many contributions; as, for example, on the variability of the sun and the periodicity of solar variations. The Art Galleries, National and Freer, have also received many valuable additions.

The General Appendix (pp. 103-497) contains 22 interesting papers on a wide range of subjects, often illustrated by plates and figures. Some of the more interesting subjects are the following: Solar radiation, by C. G. Abbot; Age of the earth and age of the ocean, by Adolph Knopf; meteorite craters at Henbury, Australia, by A. R. Alderman; the Byrd Antarctic expedition, by L. M. Gould; Modern deep-sea Oceanography, by C. O'D. Iselin; Bird banding in America, by F. C. Lincoln; Present status of light Therapy, by A. C. Seward.

The Romance of Research; by L. V. Redman and A. V. Mory. Pp. x, 149. Baltimore, 1933 (Williams and Wilkins Co., $1.00).—This last number of the Century of Progress series attains the standard of excellence that we are led to expect by the previous numbers. A large array of diverse conquests in the onward march of scientific research is presented coherently and entertainingly. The authors have given an outline of the history, the method, and the meaning of research in its liberation of the human spirit. Their chapters are enlivened by anecdotes that will be novel to most readers—for example: Price's suicide; the naming of the spinning jenny; the origin of Tammany.

In the middle of the book we read that the study of the ductless glands "promises to lead into a real science of psychology"; and at the end we read that the sociologists are "the prophets and seers of our time." Readers can only hope that these bright words have some scientific warrant. HENSHAW WARD.

Laboratory Directions in General Physiology, 3d revised edition; by E. Newton Harvey and Arthur K. Parpart. New York, 1933. Pp. 45 (Henry Holt and Co., price $0.60).—This is an inexpensive, handy, paper-covered laboratory outline designed for student use in a non-medical course in "general" (*miscellaneous*) physiology. The print is clear and free from typographical errors and the blank side of each sheet is useful for annotations. The purposed brevity and omission of all but routine directions render the manual of little value to other instructors seeking points of technique. Economy of material and method is sometimes attained by an oversimplification and the retention of antiquated methods as in the experiments on respiratory gases. It might be pertinent to enquire whether the extensive detail of oft unimportant procedures may not cause the student to look upon the course as mere "applied" physics and chemistry when a few more carefully selected experiments would better inculcate the biological method and lay the foundations for "physiological thinking."

JOHN H. FERGUSON.

Forestry, an Economic Challenge; by ARTHUR NEWTON PACK. Pp. 161. New York, 1933 (The Macmillan Company, $1.25).—This book is a broad survey of the economic and public problems of forestry, with trenchant comments on the failures of private owners and of the public; it is in a real sense a challenge for clearer thinking and more intelligent action in meeting the forest problems of the country.

The author describes in vivid terms the history of the forestry movement, the efforts to check abuses and to bring about a better protection and handling of forests, the conflict with speculative acquisition of land by private ownership and the pressure for rapid exploitation of the timber, the establishment and organization of the system of National Forests, the development of state forestry, and the activities, both public and private, that are now under way. New conditions have arisen as a result of the virtual breakdown of the lumber industry, through over-development of plants, production of lumber beyond the power of consumption, and premature and wasteful liquidation of timber. Public forestry has made progress. Private owners are now seeking a method of stabilizing the producing industries and are looking to forestry as one possible means to accomplish the purpose. The way is opening for a new step forward in the introduction of better management of private forests, provided there is wise leadership equipped to deal with the economic situation that has arisen.

Packed in the volume are the more essential economic facts relating to forests and forestry, an interpretation of prevailing conditions, a critical analysis of the mistakes both of industry and of foresters, and the short-comings of public policies and of the private efforts. Throughout is a demand for clear thinking, based on sound economics, in regard to forest problems, an emphasis on the need of national and regional planning and on the articulation of forestry with other forms of land use in supporting industrial activities and building up a basis for community prosperity.

The book is exceedingly well written. The impartial criticisms are refreshing and should be effective in stimulating self-examination among the leaders of industry and of forestry. Mr. Pack has made an excellent and very timely contribution to forestry through the vigorous challenge in his book. H. S. GRAVES.

"*L'Apparato Motore Diesel-Elettrico e gli Impianti Ausiliari della Nave Traghetto 'Scilla'*"; pp. 61, 7" x 9½"; 9 folded plates and many diagrams. (Ercole Marella S. C., Corso Venezia 22.)—Marine engineers are constantly seeking a better solution of the problem of reconciling the high speed of the prime mover with the slow speed propeller. Steam turbines and internal combustion engines must operate at a relatively high number of revolutions per minute in order to operate economically. The designing of propellers for a given ship is a complicated problem, but in general a low rate of revolutions per minute is desirable.

Three possible mechanisms may be used in this connection: (a) Mechanical gears; (b) Electric drive; (c) Hydraulic. Of these, the last is unimportant. Before the World War little had been done in developing the mechanical and electric systems. The U. S. Navy built three colliers in 1910 which proved the applicability of the electric drive but the great impetus given to ship construction by the U. S. Shipping Board is responsible for the modern development of mechanical reduction gears. Most of the modern merchant ships such as the *Washington, Manhattan, Bremen, Europa,* etc., are equipped with steam turbines and mechanical reduction gears.

Diesel engines are limited by available metals to smaller horsepowers; and hence used in yachts, submarines, tugboats and ferryboats. Such craft require extreme maneuverability which is given by the electric drive, though it is costly and of greater weight.

This pamphlet describes an Italian-built ferryboat for automobiles and rail cars. Three Diesel motors drive electric generators from which power is controlled to two electric motors (one on each of the two propeller shafts). The ship is 109 meters in length and has a maximum speed of 17 miles per hour, at 5,000 horse-power. The description given is very complete and makes clear several fine features of design, as the direct control of the propelling motors from the captain's bridge. In one of our American Diesel electric tugboats this feature alone saved the sum of $100 on lines and fenders, during the first month. The plates show the electrical circuits, arrangement of machinery and details of Diesel engines, motors and switchboards. H. L. SEWARD.

OBITUARY.

DR. ERNST HARTERT, the distinguished ornithologist, died on November 10 at the age of seventy-four. German by birth, he spent much of his life building up Lord Rothschild's collection of birds at Tring. His study of the palaearctic birds was also rich in results.

DR. JOHN JOLY, professor of geology and mineralogy at the Dublin University since 1897, died on December 8 at the age of seventy-six.

Dr. John Edward Marr, the distinguished English geologist, died on October 1 at the age of seventy-six. He was professor of geology at Cambridge from 1917 to 1930.

Dr. Olaf A. Peterson, curator of mammalian paleontology at the Carnegie Museum in Pittsburgh for 33 years, died on November 12 at the age of sixty-eight.

Dr. Frederick Lincoln Chase, the astronomer, acting director of the Yale Observatory from 1910-1933, died on November 9 at the age of sixty-eight.

Dr. Roscoe Wilfred Thatcher, president of Massachusetts State College from 1927 to 1932, died on December 6 at the age of sixty-one.

Dr. John Merrill Poor, professor of astronomy at Dartmouth College from 1917, died on December 12 at the age of sixty-two.

PUBLICATIONS RECENTLY RECEIVED.

Fossil Floras of Yellowstone National Park and Southeastern Oregon. Carnegie Institution of Washington, 1933.

Mineral Resources of the United States 1930. Part II. Nonmetals. Bureau of Mines, Washington, D. C.

On the Mineralogy of Sedimentary Rocks; P. G. H. Boswell. New York, 1933 (D. Van Nostrand Co., London, Thomas Murby & Co., 21s.-net).

History of the Theory of Ore Deposits with a chapter on The Rise of Petrology; by Thomas Crook. New York, 1933 (D. Van Nostrand Co., London, Thomas Murby Co., 10s. 6 net).

Atitlan. An Archaeological Study of Ancient Remains on the Borders of Lake Atitlan, Guatemala; by Samuel K. Lothrop. Carnegie Institution of Washington, 1933.

The Book of Chilam Balam of Chumayel; by Ralph L. Roys. Carnegie Institution of Washington, 1933.

America Self-Contained; by Samuel Crowther. New York, 1933 (The Chemical Foundation, Francis P. Garvan, President).

The Geology of Texas. Volume I. Stratigraphy; by E. H. Sellards, W. S. Adkins, and F. B. Plummer. Austin, 1932 (University of Texas Press).

Physics of the Earth—VI. Seismology. Bulletin No. 90, October, 1933; National Research Council of the National Academy of Sciences, Washington, D. C. (Price paper $2.00, cloth $2.50.)

A Forest of the Coal Age; by B. E. Dahlgren. Geology Leaflet 14. Field Museum of Natural History, Chicago, 1933.

Pflanzen-Thermodynamik; by Kurt Stern. Berlin, 1933 (Verlag Julius Springer, RM 32, bound RM 33.20).

Thomas Young, F.R.S. Philosopher and Physician; by Frank Oldham. London, 1933, Edward Arnold & Co. (New York, Longmans, Green & Co., $2.40).

Introduction to Physical Chemistry; Alexander Findlay. New York, 1933 (Longmans, Green & Co., $3.00).

Carnegie Institution of Washington. News Service Bulletin, Vol. III, No. 10. The Birthplace of George Washington.

Éléments D'Optique Géométrique; by Pierre Copel. Paris, 1933 (Gauthier Villars, 25 fr.).

Physik für Jedermann von A. Haas. Berlin, 1933 (Julius Springer, bound RM 6.80).

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The following is an example of the system of references employed, the volume being given in heavy faced type:

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FEBRUARY 1934

LATE-GLACIAL FEATURES OF THE QUINNIPIAC-FARMINGTON LOWLAND IN CONNECTICUT.[1]

RICHARD FOSTER FLINT.

INTRODUCTION.

The Connecticut Valley lowland, developed in comparatively weak Triassic rocks with general north-south strike, is partially divided by a great longitudinal ridge of basalt (Talcott Range-Holyoke Range) into two unequal parts. East of the ridge lies a relatively broad lowland drained by the Connecticut River; west of the ridge lies a relatively narrow lowland, here termed for convenience the Quinnipiac-Farmington lowland,[2] drained chiefly by the Quinnipiac and Farmington rivers (Fig. 1). The Quinnipiac, rising near Plainville, flows south-

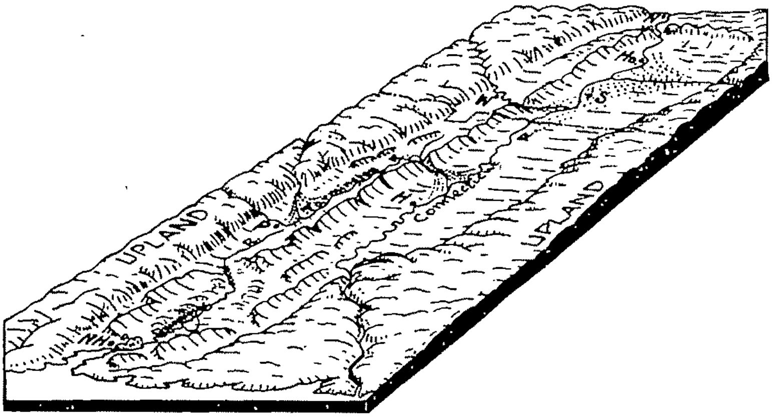

Fig. 1. Index diagram of a part of the Connecticut Valley lowland, showing the longitudinal ridge that divides it into two parts. The long axis of the block lies north-south, and is approximately 90 miles in length. NH = New Haven; P = Plainville; H = Hartford; W = Westfield; S = Springfield; Ho = Holyoke; N = Northampton.

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[1] Based in part on a study made during the summer of 1932, with aid from the Dana Research Fund of Yale University, to supplement and correct the writer's earlier work in the region (Flint, 1930).

[2] The Lower Sandstone Lowland of Davis (1898, p 182).

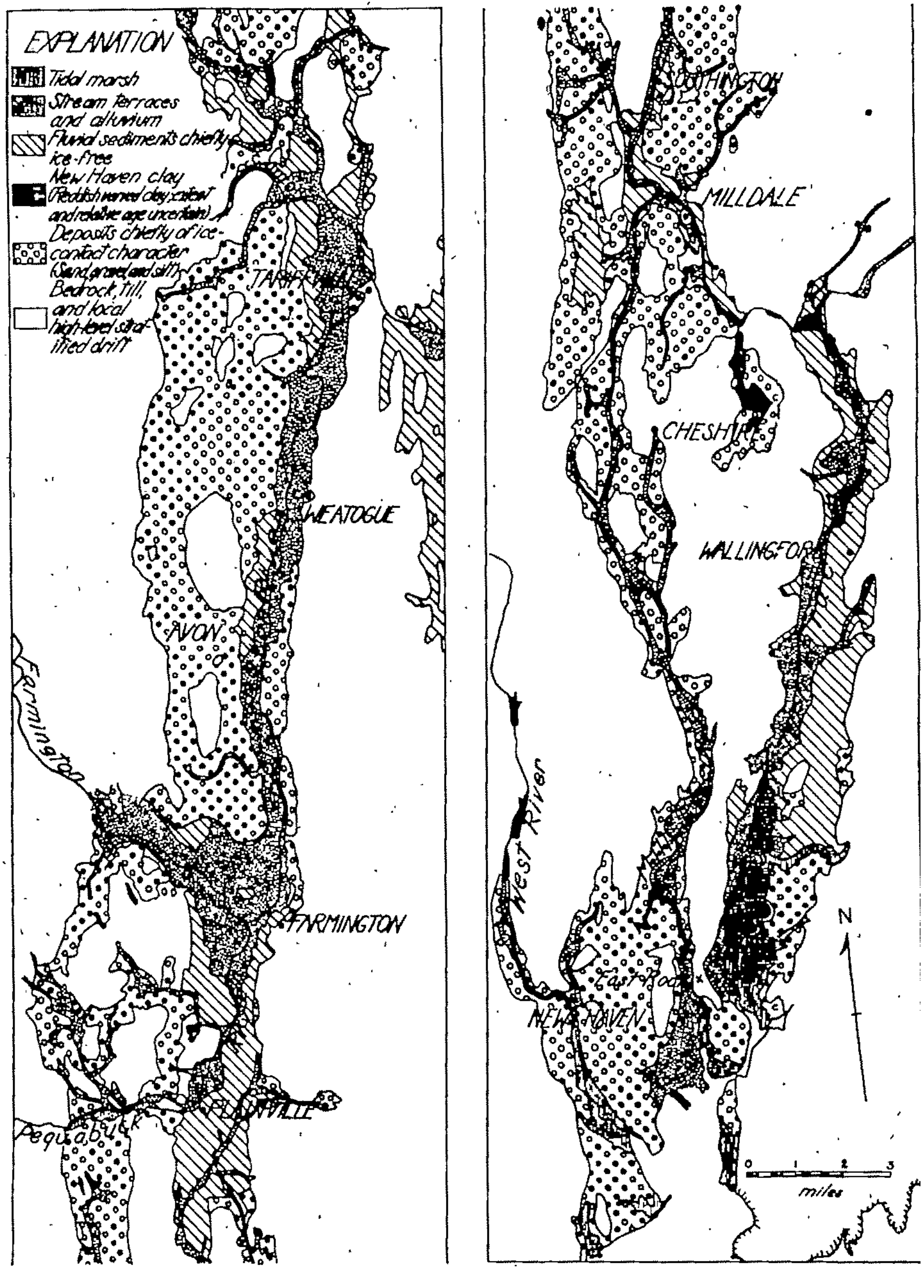
EXPLANATION
Tidal marsh
Stream terraces and alluvium
Fluvial sediments chiefly ice-free
New Haven clay (Reddish varved clay; extent and relative age uncertain)
Deposits chiefly of ice-contact character (Sand, gravel and silt)
Bedrock, till, and local high-level stratified drift
TARIFFVILLE
WEATOGUE
AVON
Farmington
FARMINGTON
PLAINVILLE
Pequabuck
SOUTHINGTON
MILLDALE
CHESHIRE
WALLINGFORD
West River
East Rock
NEW HAVEN
N
0
1
2
3
miles

Fig. 2. Map showing distribution of late-glacial deposits in the Quinnipiac-Farmington lowland, and places referred to in text.

ward to Long Island Sound at New Haven, more than 25 miles distant. The Farmington and its tributary the Pequabuck emerge into this trough from the upland to the west, and flowing north for nearly 20 miles, turn again (at Tariffville) through a gap in the basalt ridge to join the Connecticut.

The late-glacial deposits in this lowland consist chiefly of stratified drift. Ice-marginal phenomena in the form of kettled stratified deposits are abundantly present, their distribution seemingly having been controlled by the configuration of the lowland. There is apparent no alignment of these features with similar phenomena in the adjacent lowland drained by the Connecticut. It seems probable therefore that the last ice sheet disappeared from the uplands while leaving in the lowlands independent residual tongues and isolated masses of ice. When at length the ice had nearly disappeared even from the valleys of the lowlands, the almost ice-free valley floors were aggraded by streams of meltwater loaded with glacial débris; and still later, when the discharge of meltwater ceased and the runoff diminished to postglacial proportions, the valley fills were locally terraced by downcutting streams.

In addition to these deposits, there is near the mouth of the Quinnipiac a body of varved clay whose time relationship to the deposits adjacent to it is uncertain.

The principal types and generations of stratified deposits (Fig. 2) may be designated as follows: (I) deposits chiefly of ice-contact character, (II) New Haven clay, (III) deposits built up in areas from which all but a few residual ice masses had disappeared, and (IV) stream terraces and alluvium.

DEPOSITS CHIEFLY OF ICE-CONTACT CHARACTER (I)

The ice-contact deposits are highly variable in composition and stratification. They consist of gravel, sand, and silt, commonly interbedded and in many exposures poorly sized. Fluvial crossbedding predominates, but deltaic stratification and horizontal lamination are also present. The bedding records local currents that moved with varying strength in many directions, with southward movement predominating, even in areas whose drainage is now northward. Numerous variations within short distances both horizontally and vertically are common. Some exposures record disturbances during deposition, such as might be caused by slumping of mounds and banks of débris, and dumping of débris from wasting ice. In one locality (Montowese, in the lower Quinnipiac Valley) deposits of this type are overlain by a veneer resembling till, suggesting local ice movement after the deposition of stratified drift. All of these features appear to be characteristic of stratified deposits formed in the presence of ice which, melting irregularly, gave origin to currents highly variable in direction and intensity.

These deposits are dominantly red and pinkish, thereby indicating derivation chiefly from the red bedrock that underlies the lowlands. At the extreme western border of the Quinnipiac-Farmington lowland, however, the red sediments are adulterated with buff and drab materials derived from the crystalline rocks characteristic of the adjacent upland. The influence of the upland débris is especially noticeable at those points where streams emerge from the upland. Between such points red or pinkish material is not infrequently found resting directly against the upland margin.

This red to pink color is so common in the ice-contact deposits, and appears so uncommonly in the younger deposits, that it can be used throughout much of this region as a fairly reliable criterion of the ice-contact type of sediments.[3]

Broad undulating plains marked by shallow closed depressions, narrow constructional terraces locally with ice-contact faces and deep kettles, crevasse fillings, and isolated knolls apparently constructional, combine to characterize the surface form of these deposits, a form which in most places distinguishes them clearly from those of later age. Form combines with stratification to suggest deposition against, around, and upon discontinuous masses of wasting ice.

Within this category there are a number of individual local deposits, some of them at relatively high elevations. Far more conspicuous than these is an extensive mass, apparently a unit, traceable from near the Massachusetts State Line almost continuously south to New Haven. It has an irregular long profile inclined southward, with a total vertical descent of more than 300 feet. The sediments that compose this mass must have accumulated through a considerable time, the escaping water following various channels accidentally offered by the bedrock surface exposed by the wasting ice. Several local baselevels may have affected the deposition of this mass of sediments.

[3] It has not been found reliable in the vicinity of Granby, where colors are mixed and correlation is uncertain.

The presence of ice-contact features in this mass throughout its extent (although such features are somewhat less conspicuous near its southern end) seems to indicate that at this stage the residual ice was contemporaneously stagnant at least through a considerable part of the distance.

Similar deposits occur in the same trough from the State Line north to Easthampton, Massachusetts, where the trough ends, but they lie at a distinctly lower elevation, were built by drainage that apparently flowed into the Connecticut, and may be of slightly later date than the mass just described.

NEW HAVEN CLAY (II)

The Quinnipiac Valley between North Haven and the narrows at East Rock (New Haven) contains a body of reddish and brownish varved clay. Exposures of this clay have been noted at only five points, but it seems probable that the deposit is continuous through a longitudinal distance of four miles. In analogy with similar deposits elsewhere, it is probably of lacustrine origin. No clay has been found south of East Rock. Where exposed, the clay is unconformably overlain by buff fluvial sand which seems to be identified with comparatively recent deposits of the Quinnipiac River. In one exposure the sand overlaying the clay is pink. If pink color were an entirely safe criterion for ice-contact deposits in this region, this exposure would indicate that the clay had been deposited prior to the last (though not necessarily pre-late-glacial) advance of ice over the area. On the other hand the pink sand might be regarded as very local, consisting of ice-contact material slightly reworked after the disappearance of ice from the area. Therefore the relative age of the clay does not seem to be indicated by the facts now available.

A somewhat similar body of clay is reported (Loughlin, 1905, p. 14) from Milldale, but it is not now exposed, and no details concerning it are available.

DEPOSITS BUILT UP IN AREAS FROM WHICH ALL BUT A FEW ICE MASSES HAD DISAPPEARED (III)

Along the Quinnipiac and Farmington rivers and their immediate tributaries there are bulky deposits of gravel, sand, and silt which were laid down by aggrading streams during and after the wasting away of the last remnants of residual ice. They have been trenched by the postglacial streams to form conspicuous terraces sloping gently and irregularly downstream.

The materials that compose these deposits are colored buff to drab, and in this respect contrast sharply with the red to pink materials of the ice-contact deposits (I). Their color probably indicates that they were derived from the crystalline rocks of the upland to the west, through the agency of streams which were no longer forced by blockades of residual ice to turn southward along the lowland margin. In most exposures these deposits are fluvially crossbedded, but in some places they appear to consist partly of laminated silts, suggesting local bodies of ponded water. In any one exposure, the stratification appears to record currents moving in a fairly uniform direction, as contrasted with the highly variable bedding in the ice-contact deposits. This may be taken to indicate closer control of drainage by existing valleys, and correspondingly less control by residual ice masses, than existed while the ice-contact deposits (I) were accumulating. In some localities there seems to be a fairly definite gradation down-valley from coarse to fine material, in contrast to the markedly variable texture of the earlier deposits.

These deposits (III) have faintly uneven upper surfaces that slope in the general direction of flow of the main streams by which they are now trenched: south down the Quinnipiac and north down the Farmington. Some of the surface irregularities appear to be caused by tributary fans; others seem to be faint former channels, but few of the channels, unlike those in the later stream terraces (IV), have the meander form. Braiding, actively aggrading streams rather than streams meandering on floodplains, seem to be indicated.

These deposits (III) unconformably overlie the ice-contact generation (I) in a number of places. Knobs and residuals of ice-contact materials locally project above the surface of the fluvial plan formed by (III), as near North Haven and Plainville. Between Plainville and Tariffville the two generations grade into each other, in that (III) was built while much remnant ice evidently still occupied the immediate valley of the Farmington, although it had almost disappeared from the region drained by the Quinnipiac, where evidence of the presence of ice during aggradation is confined to a few small depressions of doubtful kettle origin.

Generation (III) has a definite distribution. It has not been found in the valleys of Mill and West rivers, but is traceable up the Quinnipiac, continuing north of the head of that stream into the drainage of the Farmington. It is also present along the lower Farmington and its tributary Salmon Brook west of the gap in the basalt ridge at Tariffville, whereas east of the gap it widens out into an extensive plain reaching to the Connecticut River. The distribution outlined seems to indicate that the component material came out of the upland to the west, via three streams: the Farmington, the Pequabuck, and Salmon Brook; and that Mill and West rivers, tapping little of the upland area, received little upland meltwater charged with detritus.

The deposits of generation (III) along the Quinnipiac do not seem to grade into those of (I), at least in surface exposures. On the contrary the distinctness of each suggests that ice-contact conditions coupled with a supply of local red detritus, were replaced rather suddenly by comparatively ice-free conditions coupled with an abundant supply of upland detritus, unless the later streams eroded much of the red sediment and replaced it with or buried it beneath upland sediment. The event that brought about this change may have been the wasting of ice south of Plainville, introducing into the Quinnipiac valley the débris-laden discharge of both Farmington and Pequabuck rivers, which up to that time had been forced by residual ice to turn southward along the immediate base of the upland. The discharge would have made its way southward, partly over residual ice and partly over ice-contact deposits, locally burying both, and continuing the process of aggradation until after the buried ice had disappeared.

STREAM TERRACES AND ALLUVIUM (IV)

All of the stream valleys of the Quinnipiac-Farmington lowland contain terraces carved out of the deposits already described, and surfaced with fluvial veneers of variable thickness. The terraces are not distinctly paired, have margins locally scalloped, and are marked with meander scars. Because of these characteristics they appear to have been made by actively eroding streams meandering on floodplains after aggradation by meltwater had ceased. The terraces are more strongly developed along the Farmington than along the Quinnipiac, probably because of the Farmington's greater length and volume. All of the streams have developed modern floodplains of variable width.

RECONSTRUCTION OF EVENTS

In the process of deglaciation, the last ice sheet in this region disappeared from the uplands while still remaining in the valleys. Patchy stratified deposits formed here and there between ice and valley margins. As the remaining ice continued to waste away, marginal sedimentation increased, taking place beside, among, and beneath residual ice masses. At this stage ice blockades prevented the bulk of the detritus (I) from being washed along the course of the Quinnipiac, forcing it instead to move south across a low bedrock divide at Cheshire[4] and down the valley of Mill River, spreading out over the low land at New Haven in a broad pitted fluvial plain.

The deposition of the New Haven clay (II) has not yet been fitted into this sequence because its age relative to the ice-contact deposits is uncertain. The clay was deposited probably in a small ice-fed lake that may have been dammed by stratified drift below East Rock, and controlled by a narrow spillway across bedrock on the eastern side of the valley.

Ice wastage in the region between the head of the present Quinnipiac and the present great bend of the Farmington four miles to the north, seems to have permitted the Farmington and Pequabuck to begin carrying detritus southward past Plainville, building with it the broad plain (III) that extends thence down the Quinnipiac. As this plain slopes continuously south from the Farmington past the Pequabuck, and as the constituent detritus becomes finer in grain in the same direction, it seems certain that at this time the Farmington, joined by the Pequabuck, discharged southward via the Quinnipiac valley, as a braiding, depositing stream. Probably a part of its path lay over buried ice, but surface depressions formed by wastage of such ice would have been largely filled in by the stream-distributed sediments in transport across it.

The presence of residual ice at this stage in the vicinity of the big bend of the Farmington is supported by these considerations: (1) The sloping plain (III), here a terrace, seems to merge into a mass of ice-contact features near Unionville. (2) Reddish ice-contact deposits (I) in the form of constructional terraces and esker remnants extend down to elevations as low as the plain (III) between Farmington and Avon, and therefore would seem to have been protected by residual ice from burial. (3) If ice had not been present here during building of the plain (III), no means is afforded for later reversal of the drainage from a southward to a northward direction, especially between Plainville and Farmington, where the southward slope of the plain (III) is evident. If this plain had filled the valley from side to side, the Pequabuck could not later have turned north against the slope, as it could have done if later wastage of residual ice had formed a sag or depression deepening northward.[5]

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[4] This was long ago recognized by J. D. Dana (1883, p. 441).

At some time during this process, residual ice between Farmington and Avon must have wasted sufficiently to allow the Farmington to discharge northward over a steeper gradient than was offered by the Plainville route. The beginning of this discharge may be recorded between Avon and Weatogue by a fluvial deposit, now a terrace, with crossbedding indicating northward flow. Absence of this deposit south of Avon and north of Weatogue might be due in part to removal by later erosion and in part to lack of thick initial deposition as a result of the presence of ice during aggradation.

Ice wastage at the big bend coupled with the beginning of northward discharge would have caused abandonment of the plain (III) at Plainville, and diversion of the Pequabuck northward to join the Farmington at the big bend.

While the Farmington was discharging southward, the accumulation of ice-contact deposits (I), including some local reddish débris, was apparently still going on in the valley of Salmon Brook and in the valley of the Farmington south of Tariffville. When the gorge at Tariffville became cleared of ice, the drainage which had been escaping southward was diverted east through the gorge into the Connecticut valley. Eastward flow through the gorge must have been established before the Farmington began to flow north. In the district west of Tariffville, where Salmon Brook and the Farmington were confluent, exposures of laminated fine sand and silt suggest a ponding or widening of the escaping drainage, caused perhaps by the constriction downstream at the Tariffville gorge.

East of the gorge the deposits (III) spread out in a broad plain sloping toward Windsor Locks and Suffield on the northeast and toward Hartford on the southeast (Flint, 1933, p.

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[5] Crustal warping does not appear adequate to explain the drainage change, as upwarping to the north (the probable movement involved) would only increase the difficulty.

973). The gorge has been shown (Kummel, 1893, p. 386; Davis, 1898, p. 181) to be a deep narrow channel incised in the floor of a wind gap with broadly flaring slopes, and it has been suggested that the gorge was cut by the postglacial Farmington, diverted from a southward course by a drift dam at Plainville.

The Farmington east of the gorge now occupies a narrow channel nearly 100 feet deep, incised in the broad plain mentioned above. It can scarcely be maintained that the late-glacial Farmington spilled eastward across the floor of the wind gap, notching the gap floor while at the same time it built up the plain, whose apex is virtually flush with the top of the gorge. It seems more probable that the gorge existed before the plain began to be built,[6] that it became choked with fluvial débris during the building of the plain, and that when aggradation ceased the gorge was cleared out and the plain was trenched.[7]

It seems probable that when the building of the broad plain (III) east of the Tariffville gorge began, the present site of the Connecticut River was occupied by an open lake, whose varved-clay deposits seem to grade into sediments of the plain (Flint, 1933). The disappearance of the lake may have been the event that caused the Farmington to begin trenching its own broad plain. If such is the case, then from this time also must date the beginning of terracing (IV) by the Farmington throughout the long reach above Tariffville. The process must have been already well advanced in the lesser valleys, having immediately followed the stage of ice-contact deposition along Mill River[8] and West River, and having begun in the Quinnipiac valley directly the Farmington abandoned it in favor of the Tariffville route. Terracing by the lower Quinnipiac, and to a smaller extent by the other two streams at New Haven, was interrupted by rise of the sea, instituting tidal-

[6] This statement neither implies nor denies that the gorge dates from a time prior to the last glaciation.

[7] The Westfield River appears to have built analogous deposits through another gap 14 miles farther north in the same basalt ridge, and to have spread them eastward toward the Connecticut River and southward beyond the Massachusetts-Connecticut boundary.

The anomalous course of the Deerfield River between West Deerfield and Greenfield [see Greenfield, Mass.-Vt., Quadrangle] closely parallels that of the Farmington between Farmington and Tariffville, and very probably was instituted in the same way.

[8] Note, for example, the terrace at New Haven (Fig. 2).

marsh conditions. Save for such minor interruptions, downcutting accompanied by the formation of terraces appears to be still in progress in all the valleys of the region.

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SPILITE AND THE AVERAGE METABASALT.

H. W. FAIRBAIRN.

INTRODUCTION.

The neglect of the term 'spilite' in America has been commented upon many times by British and European geologists. Holmes[1] defines it as—"A basaltic rock, generally vesicular or amygdaloidal, whose feldspars have been albitized. Pyroxene or amphibole, more or less altered, and sometimes serpentinized olivine may be present." Much emphasis is placed on its high soda content by most writers. The term is commonly used in Europe and there is a large and increasing literature dealing with the origin and characteristics of this type of rock. Opinions vary regarding the petrogenic relation between spilite and other altered rocks of basaltic composition, and it is the purpose of this paper to present further data on the problem.

Current Views.

As there is no object in developing at length the history of the spilite controversy only a statement of current opinion is given here. Daly[2] and Lewis[3], the only American commentators, believe that spilite is a type of metabasalt. Wells,[4] Backlund,[5] and Sundius[6] believe that the chemical, mineralogic, and field relations of spilites and altered basalts warrant a special spilitic magma. Hackman,[7] on the other hand, finds that different authors use the term spilite for rocks of a relatively wide range of composition. Other citations might be made which emphasize these differences of opinion. It is a live problem in Europe but for the most part ignored in America.

Chemical Relations of Spilite and Metabasalt.

In a recent paper Sundius[6] plotted 19 analyses of spilitic and altered basaltic rocks on a triangular feldspar diagram.

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[1] Holmes, Arthur, Nomenclature of Petrology, p. 215, 1921.

[2] Daly, R. A., Igneous Rocks and their Origin, p. 338, 1914.

[3] Lewis, J. Volney, Bull. G. S. A., 25, p. 591, 1914.

[4] Wells, A. K., Geol. Mag., 60, p. 62, 1923.

[5] Backlund, H. G., Report of the Norwegian Expedition to Nowaya Zemlwya, **45**, p. 28; 1921.

[6] Sundius, N., Geol. Mag., **67**, p. 1. (Contains references to previous investigations by Teall, Bailey and Grabham, Flett and Dewey, Termier, Benson, Lundbohm, Geijer, Wells, Eskola, Beskow, Carstens.) 1930.

[7] Hackman, V., Bull. Comm. Géol. Finlande, **79**, p. 27, 1927.

The field in which most of the points lay was close to the Ab-An side and contained a gap which Sundius interpreted as representing the petrogenic break between the spilites near the Ab apex and the metabasalts near the An apex. Fig. 1, prepared by the writer, shows a similar diagram containing the ratios of the feldspar norms of 127 spilites and metabasalts collected from all available sources. There is no break in the continuity of the field in which the points lie and nothing to distinguish spilite as an isolated species.

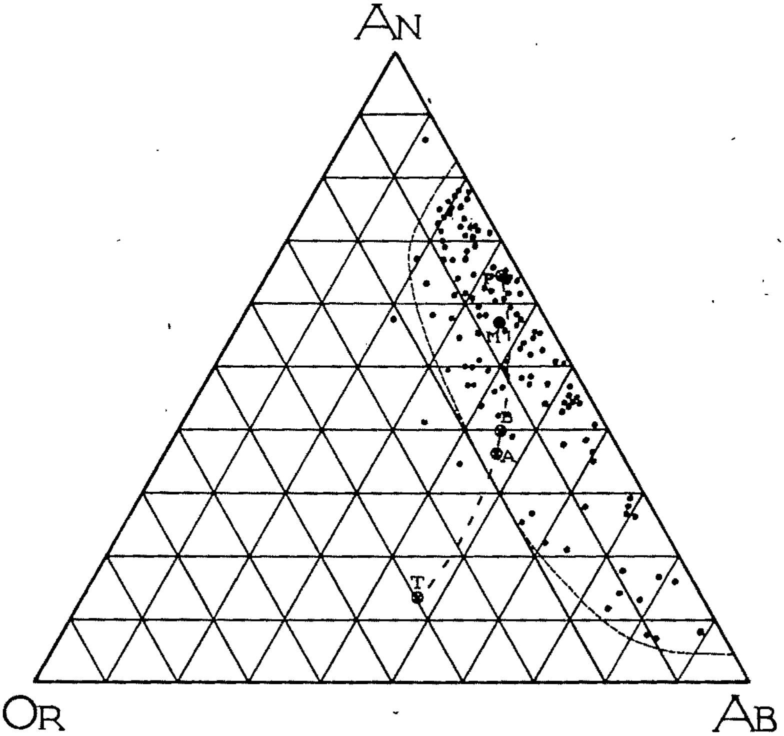

Fig. 1. Molecular volume ratios of standard An, Ab, and Or norms for 127 metabasalt analyses.

M—metabasalt.
P—plateau-basalt.
B—basalt.
A—andesite.
T—trachyte.
——— Approximate boundary of metabasalt field.

Sundius (8), in a friendly criticism of the manuscript, reiterates his belief that spilite is not of secondary origin and that

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[8] Personal communication to the author.

by consideration of the problem in one magmatic province only, e.g., the Archean, a transition such as in Fig. 1 would not occur. The writer therefore separated the Archean analyses from those of rocks of later age and averaged Na_2O and K_2O, which are well known to be high in Archean magmas. Only about one-third of the analyses are those of Archean metabasalts, but the average for Na_2O is essentially the same as that for the average Na_2O of rocks of later age. K_2O is higher in post-Archean rocks. It would seem, therefore, as far as the existing analyses go, that Archean spilite does not represent an alkaline magmatic province, and the writer can only conclude from the evidence illustrated in Fig. 1 that spilite is a metabasalt higher in soda than the ordinary type but completely gradational.

The Average Metabasalt.

This conclusion concerning spilite leads naturally to the question—"What is the composition of the average metabasalt?" The difficulties of computing such an average are admittedly greater than for unaltered rocks, but the value of such an average from the standpoint of metamorphism is undeniable. Column 1 in the Table shows the average of

TABLE I.

Comparison of Average Metabasalt with Average Basalt and Plateau-basalt.

	Average of 135 meta-basalts	Same average. Co_2- and SO_3-free	Average of 198 basalts (Daly)	Relative gains and losses (%)	Average of 43 plateau-basalts (Daly)	Relative gains and losses (%)
	1	2	3	4	5	6
SiO_2	47.56	48.59	49.06	1 Loss	48.80	0.4 Loss
TiO_2	1.72	1.76	1.36	29 Gain	2.19	20 Loss
Al_2O_3	15.00	15.33	15.70	2 Loss	13.98	10 Gain
Fe_2O_3	3.81	3.90	5.38	27 Loss	3.59	9 Gain
FeO	7.23	7.38	6.37	16 Gain	9.78	25 Loss
MnO	.22	.22	.31	29 Loss	.17	30 Gain
MgO	6.26	6.40	6.17	4 Gain	6.70	4 Loss
CaO	8.48	8.67	8.95	3 Loss	9.38	8 Loss
Na_2O	3.28	3.35	3.11	8 Gain	2.59	29 Gain
K_2O	.91	.93	1.52	39 Loss	.69	35 Gain
H_2O	3.02	3.08	1.62	90 Gain	1.80	70 Gain
CO_2	1.69	...	...		...	
P_2O_5	.38	.39	.45	13 Loss	.33	18 Gain
Rest	.22	...	...		...	
	100.00	100.00	100.00	Total Fe 4 Loss	100.00	Total Fe 16 Loss

135 metabasalts (including spilites) collected from Washington[9], Osann[10], and the current literature. It is believed to be fairly complete and includes 29 from the United States, 21 from Germany, 20 from Australia, 14 from Finland, 12 from Great Britain, 8 from Canada, 6 from Norway, 5 from Sweden, 4 from China, 2 each from France, Italy, Czecho-Slovakia, Southern Rhodesia, 1 each from Russia, Switzerland, Spain, Greece, Philippines, Madagascar, Brazil, and the Arctic. In most cases the original references were consulted and many analyses of doubtful metabasalts were discarded. The average is, therefore, as nearly correct as the number of available reliable analyses will permit.

Column 2 is recalculated from the average in 1 on a CO_2- and SO_3-free basis and the metabasalt may thus be directly compared with Daly's two average basalt analyses in columns 3 and 5. Column 3 is an average[11] of basalts in general and in respect to its Or, An, and Ab norm ratios is very close to the average andesite. (See Fig. 1.) Column 5 contains an average of plateau-basalts only[12] which is considered by Daly to be more representative of primary basalt than his earlier average. Columns 4 and 6 show the relative gains and losses of metabasalt constituents compared with each of the basalt analyses. The absolute values in these two columns are unimportant but certain features are striking. Both comparisons show that alteration of basalt leaves the SiO_2 content practically unchanged; the same is true of CaO and MgO. There is a loss in total iron, an appreciable gain in Na_2O, and of course in water content. Discrepancies arise in the comparison of the other important constituents with respect to TiO_2, Al_2O_3, Fe_2O_3, FeO, and K_2O, and those readers who are inclined to doubt the value of average analyses may here find support for their belief. The primary difficulty in this case is the impossibility of knowing the exact original composition of the rocks included in the metabasalt average and it follows that one can not arbitrarily compare it only with the average plateau-basalt, which consists of carefully selected analyses. The writer prefers, therefore, to leave open this phase of the question but maintains that the constancy of SiO_2,

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[9] Washington, H. S., Chem. Anal. of Igneous Rocks, Prof. Paper 99, U. S. G. S., 1917.

[10] Osann, A., Beitrage zur chemische Petrographie, Teil 3, Leipzig, 1914.

[11] Daly, R. A., Igneous Rocks and their Origin, McGraw-Hill Co., 1914.

[12] Daly, R. A., Igneous Rocks and the Depths of the Earth, McGraw-Hill Co., 1933.

MgO, and CaO, the gain of Na_2O and loss of total Fe, shown by both comparisons, is not accidental.

The position of the metabasalt average in Fig. 1 is also worthy of note. It falls very close to the smooth curve connecting the averages for both basalts, andesite, and trachyte. Its relation to the curve may be purely accidental and no conclusion is at present justified. It would be instructive, however, to compute averages for the altered equivalents of the remaining members of the series, andesite, trachyte, and rhyolite and test their positions also with respect to this curve.

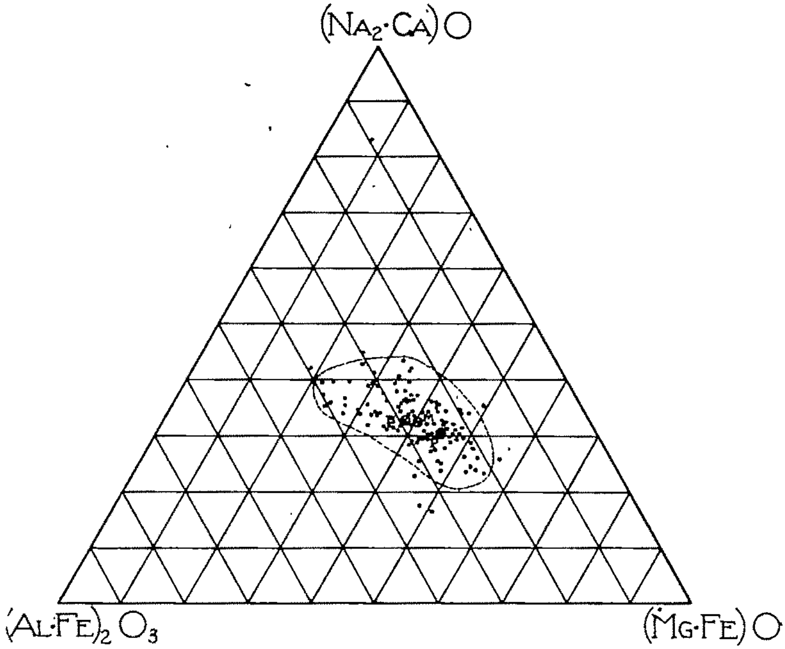

Fig. 2. Molecular volume ratios of the oxide-pairs (Na, Ca) (Mg, Fe") and (Al, Fe") for 118 metabasalt analyses.

M—metabasalt.
B—basalt.
P—plateau-basalt.

——— Approximate boundary of metabasalt field.

Fig. 2 illustrates another comparison of metabasalt and basalt with respect to the three oxide-pairs (Na, Ca), (Mg, Fe″) and (Al, Fe‴). This grouping is important as it represents those pairs of constituents which most easily replace each other in hydrothermal processes. From this standpoint a comparison of the metabasalt average with either basalt average shows no change greater than 5% with respect to any of the three pairs of replaceable constituents. The discrepancies arising from comparison of single metabasalt constituents with those of the two basalt averages are not apparent here. Na_2O, which shows an important change in the comparison of analyses, is paired with CaO which is relatively constant; FeO, which fluctuates even more than Na_2O, is paired with the practically unchanged MgO; Fe_2O_3, a third variable in the comparison, is paired with the more constant Al_2O_3. The validity, therefore, of the (Na, Ca), (Mg, Fe″), and (Al, Fe‴) grouping, established on other grounds, is here demonstrated in a practical way.

Summary.

Evidence is presented in this paper that spilite is chemically transitional to low-soda metabasalt and that the conception of a special spilitic magma is not justified. In addition an average metabasalt analysis is computed, which, when compared with both the average basalt and plateau-basalt analyses of Daly, shows that alteration was accompanied by loss of total Fe, gain of Na_2O, and constancy of SiO_2, MgO, and CaO. Conclusions regarding the alteration of the other constituents are not at present warranted.

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THE PERMIAN OF SOUTHWESTERN COAHUILA, MEXICO.

ROBERT E. KING.

Permian sediments occur in several widely scattered parts of Mexico, representing the deposits of the southern extension of the broad Permian seaway which covered a large part of the western United States. On the Isthmus of Tehuantepec, in the far south, there are little-known limestones which contain Permian fusulinids. In the northwest in Sonora there are thick fusulina limestones probably laid down in the southwestern part of the same epicontinental sea in which the Gym, San Andres, Kaibab, and Naco limestones of the El Paso region, New Mexico, and Arizona were deposited. The only place where a thick geosynclinal sequence of Permian sediments, like that of the Delaware, Guadalupe, and Glass mountains of west Texas, has so far been found in Mexico is in the southwestern part of Coahuila, near the Hacienda Las Delicias, about 260

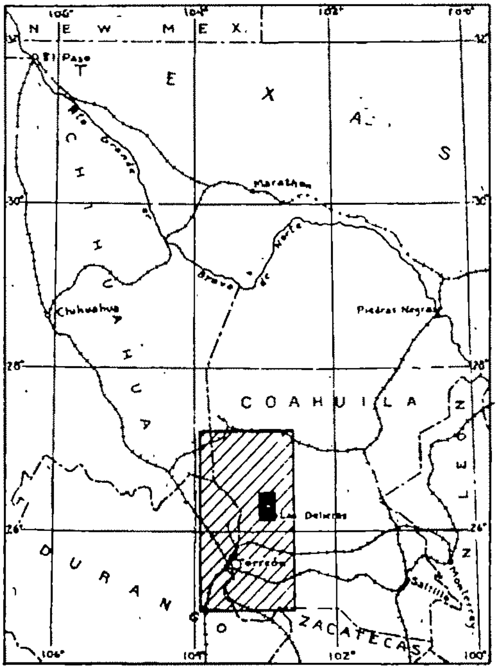

Fig. 1. Index map of northern Mexico south of Texas. The area traversed is indicated by shading, and two geological maps of it will be published later.

miles due south of the classic Glass Mountains (Marathon) section (Fig. 1). It occurs in an irregular area 14 miles long from north to south and 9 miles wide from east to west. In facies it is totally different from the Permian of Trans-Pecos Texas. The Texas geosynclinal sections are made up of shale, sandstone, and limestone, the distribution of which is controlled by the positions of continually shifting limestone reefs. The Coahuila section, however, is composed of alternations of shale, lava, and igneous detritals, with minor amounts of lenticular reef limestones. It is further notable for the profusion and excellent preservation of ammonoids in certain zones, surpassing in this respect even the important ammonoid faunas of the Glass Mountains which have been made known through the work of Emil Böse and J. P. Smith.

Permian fossils were first reported from the region of Las Delicias in 1913 by Erich Haarmann[1] and were described by Dr. Wilhelm Haack.[2] They were collected from the limestone forming a small prominence called Cerro Pichagüilla (called Pichagua by Haarmann), which was interpreted as overlying a thick series of igneous detritals containing a few imperfect fossils regarded as of Devonian age. The lower series was called the "Delicias-schichten."

In 1922 Emil Böse visited the area and in his short account[3] of it gave a rough stratigraphic section of the Permian strata west of the Noria de Malascachas, about 4 kilometers southeast of Cerro Pichagüilla. He proved that there was no Devonian present and that the so-called Delicias beds were really entirely of Permian age and in places abundantly fossiliferous. Though he noted the large amount of igneous detrital material, he included under that designation the considerable thickness of interbedded lavas in the section.

I visited the Las Delicias Permian area for eleven days in 1926, and in 1930 published[4] descriptions of some of the brachiopods collected there. In January to March, 1933, I was

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[1] Geologische Streifzüge in Coahuila. Zeitschr. d. deutsch. geol. Gesellsch., Bd. 65, Monatsb. 1, pp. 18-47, 1913.

[2] Ueber eine marine Permfauna aus Nordmexiko nebst Bemerkungen über Devon daselbst. Zeitschr. d. deutsch. geol. Gesellsch., Bd. 66, pp. 482-504, 1914.

[3] On the Permian of Coahuila, Northern Mexico. This Journal, 5th ser., 1, pp. 187-194, 1921.

See also Böse: Vestiges of an Ancient Continent in Northeast Mexico, this Journal, 5th ser., 6, p. 329, 1923, for generalized cross-section of the Malascachas area.

[4] Robert E. King: The Geology of the Glass Mountains, Part II. Univ. of Texas Bull. 3042. Austin, 1930.

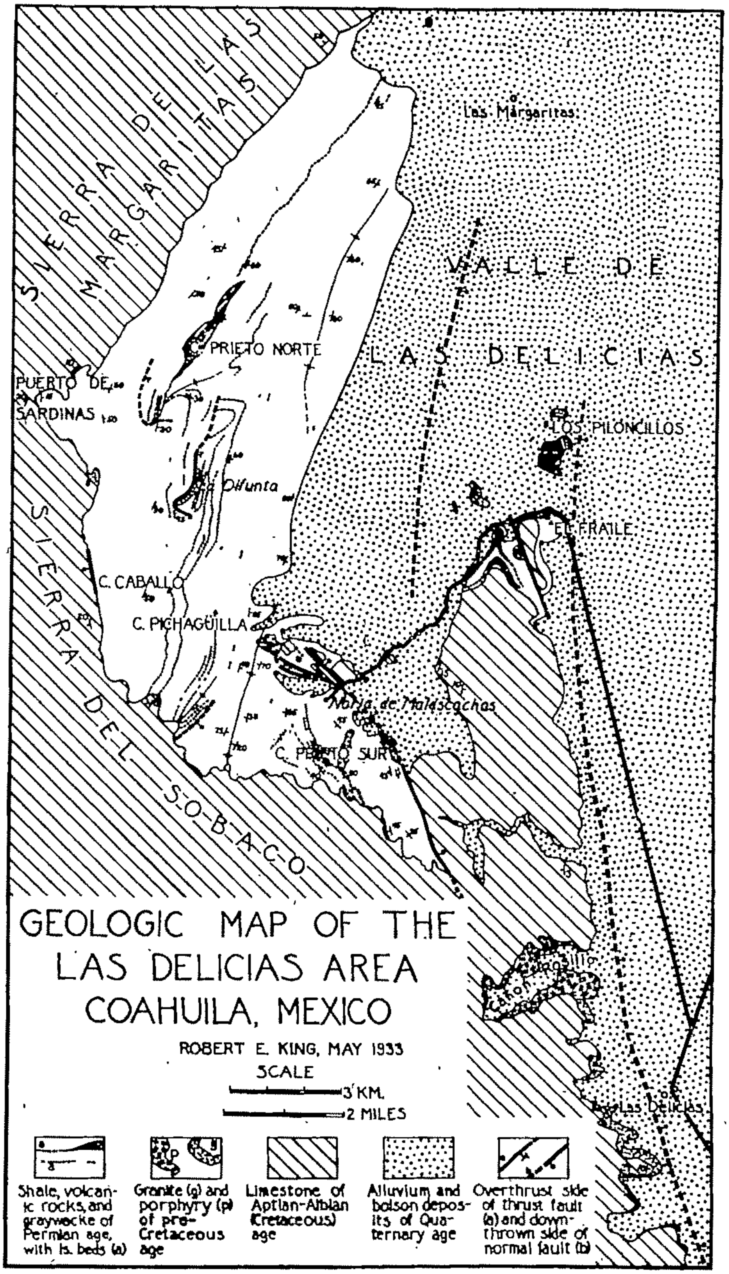
SIERRA DE LAS MARGARITAS
Las Margaritas
VALLE DE LAS DELICIAS
C. PRIETO NORTE
PUERTO DE SARDINAS
LOS PILONCILLOS
Difunta
EL FRAILE
C. CABALLO
C. PICHAGUILLA
Noria de Malascachas
C. PRIETO SUR
SIERRA DEL SOBACO
Las Delicias
GEOLOGIC MAP OF THE LAS DELICIAS AREA COAHUILA, MEXICO
ROBERT E. KING, MAY 1933
SCALE
3 KM.
2 MILES
Shale, volcanic rocks, and graywocke of Permian age, with ls. beds (a)
Granite (g) and porphyry (p) of pre-Cretaceous age
Limestone of Aptian-Albian (Cretaceous) age
Alluvium and bolson deposits of Quaternary age
Overthrust side of thrust fault (a) and downthrown side of normal fault (b)

Fig. 2. Geologic map of the Las Delicias area.

enabled by the financial aid of Professor Charles Schuchert to make a detailed study of the Permian area, constructing a map of it from pace traverses and collecting fossils. The present paper is a brief summary of the field results, a full account of which, along with a description of the fossils, will be published about two years hence.

GEOMORPHOLOGY.

Southwest of the Las Delicias Permian area lies the semi-arid Laguna plain, formed by aggradation of the Río Nazas, which heads to the southwest in the mountains of Durango. Mountain ranges of Cretaceous limestone and Tertiary basalt have been buried under the alluvium of the Nazas and now rise as isolated hills, surrounded along their margins by piedmont alluvial slopes. The southern and southwestern border of the Laguna plain is a series of arcuate ranges of intensely folded Jurassic-Cretaceous geosynclinal deposits swinging in strike from northwest to east and northeast. North and east of the plain, however, the ranges trend north-south, with long valleys between. One of these ranges is the Sierra del Sobaco, in which the Permian is brought to the surface. On each side of the Sierra del Sobaco are broad valleys aggraded by some of the farthest-reaching distributaries of the Nazas system. The Valle de las Delicias, on the east side of the Sierra del Sobaco, lies about 250 meters below the level of the flat Laguna plain, probably because of down-faulting of that valley as a graben in fairly recent geologic time.

The Permian strata are mostly exposed on a débris-mantled pediment surface below the high Cretaceous scarp. The pediment has been gullied, and in the gullies the strata are excellently exposed. Above the general pediment surface rise low ridges of limestone and some of the more resistant lavas of the section. To the east the pediment slope is overlapped by the aggraded piedmont alluvial plain which has been gradually built up as its baselevel in the Valle de las Delicias has risen, encroaching westward upon the zone of degradation.

PERMIAN STRATIGRAPHY.

For convenience the areas of Permian outcrop may be divided into three parts: the range extending north from Las Delicias, the Malascachas monocline, and the Difunta monocline, the last two being the flanks of a major syncline into which the Permian strata have been folded.

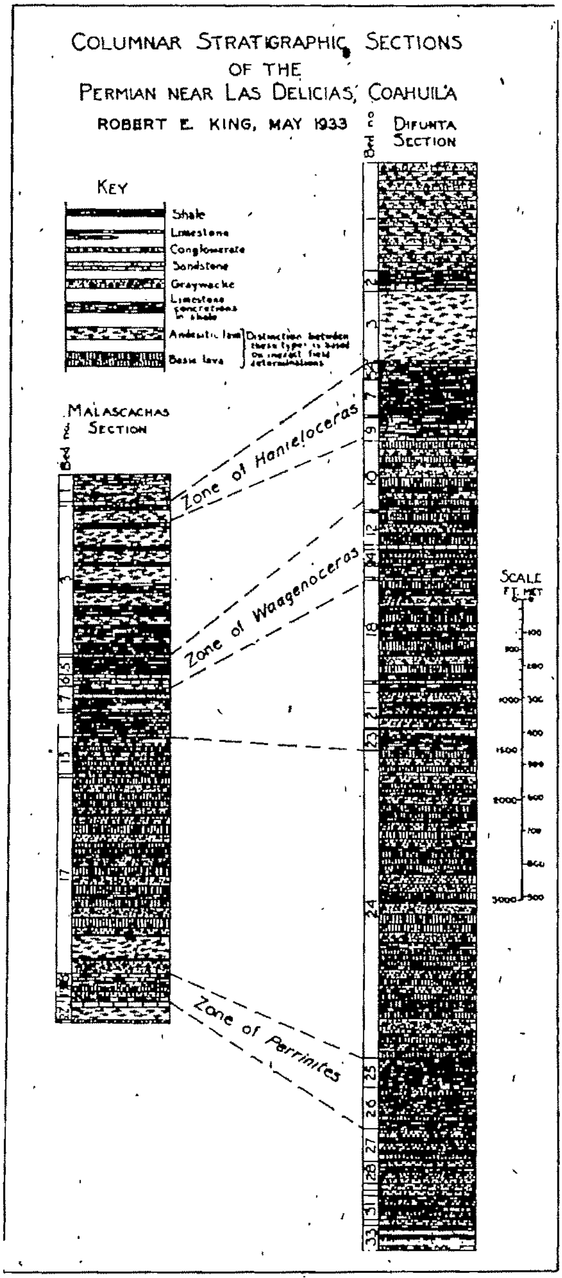

Fig. 3. Correlations of the Malascachas (5,470 feet thick) and Difunta (10,840 feet) Permian sections.

1. *Range extending north from Las Delicias.*

Extending north from Las Delicias there is a long, narrow finger of the Cretaceous of the Sierra del Sobaco, from beneath which the Permian appears in several small areas of outcrop isolated from the main Permian area by alluvium and by the Cretaceous itself. At the northern end of this range there are extensive outcrops of old Permian (and possibly Pennsylvanian) strata, from which the Cretaceous dips south and west. The lowest beds exposed are on the slopes of El Fraile and nearby hills. They are greenish-black graywacke[5] with possibly some lava, and fine-grained quartzite. Above this lies blue-grey, extremely massive crinoidal limestone. In the Cerros Piloncillos, north of El Fraile, the limestone is clearly exposed in cliffs of pure limestone, the thickness of which is at least 500 feet. In places small fusulinids were found here, but generally only crinoid stems are to be seen. It is quite likely that the limestone of the Piloncillos is a reef-like mass fingering southward into the graywacke. Cretaceous overlap cuts off the main part of the Permian strata, which overlies the thick limestone, and the limestone appears to correlate with the lower limestone of the Malascachas section.

2 and 3. *The Malascachas and Difunta monoclines.*

The Malascachas and Difunta monoclines are the east and west flanks, respectively, of a syncline into which the Permian strata are folded. The Difunta section is much thicker than the other, but the same ammonoid zones are found in both sequences. The following are condensed sections of the two areas, approximate equivalents in the two sections being placed opposite one another (see Fig. 2):

Difunta section		Malascachas section	
Upper Beds.			
	Feet		Feet
Brown lava and graywacke containing 220 ft. of shale and nodular limestone in the middle	1,975	Shale and light-colored lava	260
Black shale containing abundant concretions of hard, black limestone, bearing several species of ammonoids, including *Hanieloceras*	558	Lenticular limestone, containing large fusulinids, brachiopods, and rare ammonoids (*Hanieloceras?*)	50
Alternating lava, graywacke, and shale, containing *Waagenoceras* in lower part	962	Alternating lava, graywacke, and shale	1,480

[5] The term "graywacke" is here used for a rock of the texture of sandstone composed of fragments of unweathered basic igneous rock.

	Feet		Feet
Middle Limestone-Bearing Member.			
Dark shale, graywacke, and lava flows, with numerous ammonoids, especially *Waagenoceras*, interbedded with hard limestones up to 45 ft. in thickness	676	Shale with numerous ammonoids, containing two 15-20 ft. layers of limestone....	564
Shale, lava and graywacke, containing a few thin layers of limestone	1,685	Dark shale containing several layers of fossiliferous limestone	235
Lower Beds.			
Grey-brown lava and graywacke, containing some interbedded shale	3,075	Lava and graywacke, with several beds of conglomerate in the upper part.....	2,375
Black shale containing large concretions of black limestone bearing nuclei of *Perrinites*, some graywacke interbedded..	710	Shale bearing thin beds of dark limestone and some lava and graywacke, with abundant ammonoids of the genus *Perrinites*..........	295
Alternating graywacke, conglomerate, and dark shale....	538	Hard blue-grey limestone forming a chain of disconnected lenses. Contains a few silicified corals, many small crinoid stems, and abundant oolites in certain layers. Lithologically like the crinoidal limestone of El Fraile and Los Piloncillos	55
Interbedded shale and graywacke with lenses of limestone, in the form of rounded nodules up to 5 ft. in diameter, lithologically like the limestone of Los Piloncillos	65	Lava and graywacke.......	158
Graywacke, shale, and conglomerate of igneous pebbles and blue limestone	600		
	10,844		5,472

The lavas in the sections are generally hard to distinguish from the graywacke, as both are deeply weathered. Some more basic layers of lava are made up of spheroids which exfoliate in sheets like onion skins. This seems to be a type of weathering and is not "pillow structure." The extrusive or intrusive origin of the igneous sheets cannot in every instance be determined by the field relations, but from the presence of graywacke in association with them it is known that there was a great deal of effusive activity. There is a sheet of fine-grained granite 2.5 kilometers S. 13° E. of the Noria de Malascachas which probably was derived from the intrusion of granite underlying the Permian. In two other places there are definitely intrusive igneous rocks which crosscut the dip of the strata, but these are megascopically similar to the adjacent flows and perhaps were contemporaneous with them and feeders to them. It is possible that many of the igneous sheets are intrusive, and are perhaps contemporaneous with the flows or with the granite which was intruded subsequently.

Summary of Permian Stratigraphy.

The application of a formation or group name to the Permian strata of the Las Delicias area seems hardly justified, since they embrace nearly the whole of the Permian system. For that reason, I do not favor the use of Haack's term "Delicias-schichten" as a group name, but like Böse I prefer its use simply as a designation of the volcanic facies developed near Las Delicias. Nor do there seem to be good reasons for subdividing the section into formations, for the lithology and thicknesses are so variable, and accurate key beds so few, that the sections can only be split up into general units.

At the base of the section is the limestone of Cerros Piloncillos and associated igneous rocks. The limestone of Los Piloncillos appears to have been a reef fingering out into lava and graywacke toward the south. On the basis of lithology the lenticular limestone at the base of the Malascachas section seems to be one of the layers extending out from the Piloncillos reef nucleus. While this limestone does not appear in the lower part of the Difunta section, there are large blocks of lithologically similar limestone just above the Puerto de Sardinas which may indicate derivation from a local uplift of the Piloncillos limestone in the adjacent sea floor.

The occurrence of *Perrinites* in the overlying shales indicates correlation of them with the Leonard formation of the Glass Mountains section. Possibly the Piloncillos limestone and associated lava and graywacke are of Wolfcamp age.

Above the *Perrinites* horizon are 2800-4800 feet of igneous material, which are followed by the middle limestone-bearing member of the section, the zone of *Waagenoceras dieneri*?. The lower part of this member is alternating shale and thin limestones, and in the Difunta section contains interbedded igneous material. This is overlain in the Difunta section by the thick, persistent limestone forming Cerro Caballo, and its supposed northern equivalent, the thick lenticular limestone of Cerro Prieto. Several other prominent limestones follow, separated from one another by shale, graywacke, and lava. The limestones are made up almost entirely of sponges and crinoid stems; in some layers fusulinids are abundant. *Chonetes deliciasensis* is very common. Thin limestones in the intervening shales contain abundant *Waagenoceras*, *Medlicottia*, *Gastrioceras*, and *Stacheoceras*. In the Malascachas section the equivalent of the Cerro Caballo limestone is probably that which caps Cerro Prieto Sur and thickens to the southeast, reaching 200 feet where it is overlapped by the Cretaceous. Above the limestone are alternating shale and limestone; unlike the Difunta section, there is little igneous material here. In this group there are abundant ammonoids comprising a number of genera. The presence of *Waagenoceras dieneri*? indicates the correlation of this member with the Word formation of the Glass Mountains section.

Above the limestone-bearing member of both sections are alternating lava, shale, and graywacke, containing in the lower part of the horizon a narrow species of *Waagenoceras*.

This is followed in the Difunta section by black shale containing abundant concretions of hard black limestone in the region east of La Difunta. The concretions commonly contain nuclei of ammonoids, of which the most significant form is *Hanieloceras*, a member of the Cyclolobinae more advanced than *Waagenoceras* and transitional from it to the late Permian *Cyclolobus*.[6] This is undoubtedly younger than any known ammonoid horizon of the Glass Mountains, and must correlate with the upper dolomites belonging to the Capitan formation. Toward the south lenticular limestone layers appear at the horizon, including Cerro Pichagüilla, formed of a layer of dark-grey limestone about 60 feet in thickness which contains the Permian coral and brachiopod fauna described by Haack (op. cit.). The Pichagüilla lens ends abruptly a hundred meters north of the hill, but toward the south it can be traced, with less thickness, to the Cretaceous scarp. Lesser beds of sponge and *Prorichthofenia*-bearing limestone appear below it. This ammonoid zone is not certainly known in the Difunta section, though near the top of that section there is a limestone containing rare ammonoids, including what may be a *Hanieloceras*.

Above is a non-spheroidal porphyritic lava, lighter in color and more resistant than the spheroidal lavas of the section. In the Difunta sequence this is followed by a concretionary shale which contains rare ammonoids, then over 1000 feet of alternating brown lava and graywacke.

Conditions of deposition of the Permian.—Permian sedimentation was interrupted by outpourings of lava. From the eruptive activity is derived the graywacke, probably mainly the result of erosion of the lavas where these solidified or were uplifted above wave base (see Fig. 2). The lava and graywacke combined comprise two-thirds of the total thickness of the Difunta section, but in the Malascachas sequence the proportion is much lower, and limestones, though their aggregate thickness is relatively small, are somewhat thicker. The latter sequence is considerably thinner than the Difunta, the difference being entirely due to the greater thickness of basic igneous material in the latter. It seems apparent, therefore, that the source of the lavas was from the west, away from the Llanorian landmass, and therefore from beneath the geosyncline itself.

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[6] The genus *Hanieloceras* was proposed by A. K. Miller in Age of the Permian Limestones of Sicily, this Journal, 5th ser., 26, p. 413, 1933.

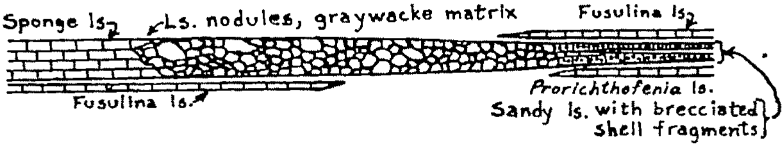
Sponge ls.
Ls. nodules, graywacke matrix
Fusulina ls.
Fusulina ls.
Prorichthofenia ls.
Sandy ls. with brecciated shell fragments

Fig. 4. Diagram to show lateral change from a massive sponge limestone into a nodular one, with nodules up to 30 feet across, cemented by igneous detritals. Vertical scale exaggerated.

The limestones of the section are interesting because of their striking lateral changes. The lowest limestone, that of the Cerros Piloncillos, is a massive crinoidal reef fingering out laterally into lava and graywacke. On the margins of the reef there are a few places where hard nodules of blue-gray limestone are cemented by igneous sand. This phenomenon is still more striking in the median limestone group. Where one of these limestones is traced laterally it changes from massive sponge limestone 10 feet or more in thickness to nodular limestone cemented by igneous detritals (see Fig. 3). Some of the nodules are as much as 30 feet long and 15 feet thick. The nodular limestone generally thins gradually and resolves itself into several thin layers of sandy limestone almost made up of broken shell fragments, commonly with abundant *Chonetes deliciasensis*. In a short distance along the strike these may again give place to nodular and then massive limestone. In places the massive limestone is evidently formed partly of calcareous algae, and it is likely that these, with the sponges, played a large part in its formation. Fusulinid limestones are irregular in distribution, as are the limestones made up of clusters of *Prorichthofenia*. The former may occur in layers above or below the main limestone, as a lateral transition phase between sponge limestone and sandy limestone, or interbedded with the massive sponge beds. Some of the limestones are mere lumps, of 50 or more feet in thickness, but with a lateral extent of only 200-300 feet. The massive limestones probably are the remains of reefs which grew above the general level of the sea floor; the nodular limestones perhaps were formed by the breakup of the margins of the reefs by the lavas.

The Permian of the Las Delicias area is much thicker than the corresponding strata in Trans-Pecos Texas, but the thickness of the purely sedimentary part is probably about the same as in the latter region. It is likely that the Las Delicias Permian was laid down in the southern continuation of the Texas Permian geosyncline, and by analogy the source of sediments would have been from the east, though there is no direct evidence for that conclusion. In contrast to the Texas Permian, that of southwestern Coahuila was strongly folded, thrust, and intruded by granite before Cretaceous time.

POST-PERMIAN INTRUSIVE ROCKS.

Granite and its differentiation products crop out along the east foot of the Sierra del Sobaco west of Las Delicias for a distance of 8 kilometers. A valley 2 kilometers N. 75° W. of Las Delicias is the dividing line between coarse-grained holocrystalline hornblende granite on the south and a complex of porphyry to the north. Four kilometers S. 10° E. of Las Delicias, at its southernmost outcrop, the granite has an intrusive contact with brown dense limestone which bears traces of fossils, including a possible crinoid stem. The limestone is highly mineralized with quartz and specular hematite. The directly overlying Cretaceous limestone is unmetamorphosed.

The porphyry forms several hills at the mouth of Cañon Rosillo and extends up that valley for 2½ kilometers. In the eastern outcrops there is some quartz porphyry and a small amount of fine-grained diorite. Farther up the canyon the porphyry is darker and resembles the lava interbedded with the Permian sediments to the northwest. There are some dikes of quartz porphyry even here.

The porphyry complex probably represents the marginal phase of a granite batholith where it comes in contact with the Permian lavas. Cañon Rosillo lies on the strike of the

Malascachas monocline. The limestone south of Las Delicias may be pre-Permian, though the absence of other pre-Permian strata from the region suggests that it, too, is of Permian age. The Cretaceous overlies the granite unconformably, and the old surface appears to have been completely baseleveled before the new phase of sedimentation began.[7]

LOWER? AND MIDDLE CRETACEOUS.

The Permian strata, and the granites intruded into them, are unconformably overlain in the Sierra del Sobaco by nearly 3000 feet of massive limestones that dip to the west toward the Valle de Acatita. The eastern scarp, facing the Permian area, is a sheer cliff which shows almost no bedding. In places the lower limestones contain an abundance of *Orbitolina texana*, while the massive limestone above is formed largely of rudistids. The eastern face has thick layers of gypsum interbedded with the massive limestone, and elsewhere nearly two-thirds of the Cretaceous is gypsiferous.

The Sierra del Sobaco evidently was the site of a great rudistid reef, growing rapidly and interfingering laterally with gypsiferous lagoon deposits. The absence of a basal conglomerate as a rule, and its fineness of grain when present, show that the Permian and the granite were baselevelled before the transgressive Cretaceous deposition began. Not far away to the south and west, however, occur older Mesozoic formations.

No Upper Cretaceous is present within the Permian area studied, but such is known to the north and to the south, and evidently once covered the whole of the Permian.

STRUCTURAL GEOLOGY.

Pre-Cretaceous Structure.—The Permian strata are folded into a broad syncline, the two flanks of which are here termed the Difunta and Malascachas monoclines (see Fig. 2). The average dip on both flanks is 45°, but ranges from 15° to vertical. As the Cretaceous lies nearly flat above the greater part of the Permian area, the pre-Cretaceous structure has been but little altered by later movements. The axis of the major Permian syncline trends N. 12-20° E., and the average strike of the Difunta monocline is nearly the same, varying from N. 7° to 37° E. In the Malascachas monocline, however, the strike swings from N. 10° E. near the synclinal axis to N. 40° W. south and southeast of the Noria de Malascachas, almost parallel to the Cretaceous scarp to the southwest.

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[7] Böse (op. cit., p. 193) reported a dark igneous detrital layer about 1 or 2 meters thick resting upon the eroded surface of the granite and beneath the Cretaceous limestone. I was unable to find this. In any case, the layer might be of Cretaceous age and does not prove that the granite is pre-Permian.

That the Permian strata of the region have been strongly deformed by folding is evident from the high dips found in nearly all parts of the outcrop. This may be further complicated by overthrust faults on the west flank of the syncline as suggested by certain field relations.

Besides the thrusts there are a number of normal faults, mostly of too small a throw to be mapped. These may in part have been formed in Cenozoic time, when the large normal faults of the region had their origin.

The Lower Permian strata of the El Fraile-Piloncillos group to the east of the main Permian area show no clear connection with the latter, though it is possible that they are uplifts in the core of the anticline of which the Malascachas monocline forms the western flank. The granite farther south may have been intruded into the anticlinal core.

As noted above, it is believed that the geosyncline in which the Permian sediments and igneous detritals were laid down was the southern continuation of the Permian geosyncline of Trans-Pecos Texas, and that the source of sediments was the hinterland of Llanoria, which lay to the east. The swing in strike of the Malascachas monocline toward the southeast is very significant, as it may be a major change in strike direction of the Permian folds corresponding to the swing in strike from northwest to east in the Jurassic-Cretaceous folds near Torreón. This conclusion is supported by the reflection of this change in strike in the overlying Cretaceous, accounting for the arcuate form of the Sierra del Sobaco.

Whereas in Trans-Pecos Texas the Permian was but slightly deformed before Cretaceous time, the Permian of southwestern Coahuila was strongly folded and even overthrust, as is the Pennsylvanian of the Marathon basin (though not to as great a degree). For that reason it is concluded that the Permian geosyncline of southwestern Coahuila lay on the site of, or close to, the southern continuation of the pre-Permian Marathon geosyncline, the sediments of which are either buried beneath the Permian or concealed by the alluvium and Cretaceous sediments to the east. The folding of the Permian, which probably took place near the end of that period, was the last phase of orogeny affecting the sediments of this geosyncline, and the folds were beveled off in early Mesozoic time. Since undoubted pre-Permian rocks are not exposed, it cannot be said whether late Pennsylvanian folding took place here as in the Marathon region.

Post-Cretaceous Structure.—In all the region north of the Laguna plain and east of the Torreón-Chihuahua railroad line the Cretaceous sediments and the later basic lavas are folded in broad domes or low-dipping faulted cuestas. The Sierra del Sobaco is capped by massive Middle Cretaceous limestone dipping to the west at a low angle, turning down on the west side to dips of 30°-45°, to pitch under the Valle de Acatita. The eastern face of the range toward the Valle de las Delicias is obviously a fault scarp. Behind the front of the range a fault extends northwest from north of the head of Cañon Rosillo to northwest of the Noria de Malascachas, bringing down Cretaceous on the northeast in contact with Lower Permian on the southwest side. North of the Noria de Malascachas this fault splits into several minor radiating ones which die out toward the west in the Permian. Another fault extends north through the valley between the El Fraile-Piloncillos hills and the main Permian area, as shown by the west dip of the Cretaceous of the Cerro el Panal toward the Permian, without any exposure of an east-dipping flank between there and the edge of the Permian area.

Northeast of the Sierra del Sobaco is the high mountain knot of Presa de Mata, from which ranges of Cretaceous limestone radiate in all directions. North of this knot the prevalent strike changes from north-south to east-west, and along the north side of the railroad line from Monclova to Sierra Mojada lies the high east-west Sierra de la Madera, the south side of which is probably a fault scarp. The Cretaceous is but gently folded as far east as the eastern side of the State of Coahuila, which is crossed by the northern fork of the Eastern Sierra Madre.

By contrast, the ranges south of the Laguna plain and west of the Torreón-Chihuahua railroad line are part of a strongly folded cordillera of Jurassic and Cretaceous strata.[8] This cordillera makes a sharp bend near Torreón from an east-west to a northwest strike. Böse has shown that the folded cordillera was the site of a geosyncline bordering, in Jurassic and Neocomian times, a broad landmass which was covered by the Mesozoic sea for the first time in the Aptian. The area described in the present report is entirely within the area of the former Jurassic land, where the Cretaceous is now only gently folded. The Jurassic landmass was the direct successor of Llanoria of Paleozoic time, but in the Jurassic the periphery of the land had been extended to include the area folded at the close of the Paleozoic.

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[8] Böse, Emil: Vestiges of an Ancient Continent in Northeast Mexico. This Journal, 5th ser., 6, 1923.

Kellum, L. B., Reconnaissance Studies in the Sierra de Jimulco, Mexico. Bull. Geol. Soc. Am., 43, pp. 541-564, 1932.

The Torreón bend of the cordillera is reflected in changes in strike from north-south to northwest-southeast in the Cretaceous ranges of the area studied, and in the Sierra del Sobaco this swing in Cretaceous strike corresponds to the swing in the strike of the underlying Permian. The relationship of these three facts points strongly to the conclusion that the margin of the Jurassic landmass was the belt of Paleozoic folds, and that a southwestward-projecting salient in these folds formed a buttress around which the Mesozoic cordillera was bent.

The Aptian and Albian limestone was deposited over the whole region, apparently regardless of the limits of the former Jurassic geosyncline. It was overlain by outpourings of basalt along the margin of the old landmass, and the whole region was folded in late Cretaceous or early Cenozoic time, though the deformation was intense only where the Cretaceous was underlain by a thick Jurassic section, while the area to the north and east, where the basement complex and Paleozoic folds lay near the surface, was only gently folded.

Probably in late Cenozoic time, the whole of the gently folded area was block-faulted. The faulting along the front of the Sierra del Sobaco dropped the Valle de las Delicias as a graben, accounting for its present low elevation, and probably similarly gave rise to most of the undrained bolsons which are an important feature of the region.

IOWA CITY,
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CORRELATION STUDIES OF THE CENTRAL AND SOUTH CENTRAL PENNSYLVANIA BENTONITE OCCURRENCES.[1]

R. R. ROSENKRANS.

The discovery of beds of altered volcanic ash in the Ordovician of Kentucky, Alabama, and Tennessee reported by Nelson (29) in 1920 led to a search for other occurrences in the Ordovician strata of the Appalachian province. Numerous papers have since been published dealing with deposits at isolated points throughout the eastern United States. In 1928 Bonine and Honess (17) presented the results of a brief study of some outcrops in central Pennsylvania. This study was primarily of a petrographic nature and showed definitely the bentonitic character of these deposits. Whitcomb (45) has used the outcrops of five beds of bentonite in the Salona and a chert horizon associated with one of these beds for correlation of this formation over a considerable area in central Pennsylvania, thus illustrating the value of bentonite beds as key horizons for use in close stratigraphic correlation.

It is the purpose of this paper to present the results of detailed stratigraphic and petrographic studies of these beds. The work of Whitcomb (45) has been greatly extended, numerous additional outcrops have been discovered and studied, and an additional bed in the Salona has been recognized and traced. Moreover, six beds of Pre-Salona age have been studied.

STRATIGRAPHY.

As pointed out by Field (14) the faunal and lithologic peculiarities of the central and south central Pennsylvania Ordovician formations make it possible to treat their area as a separate province within the Ordovician terranes of eastern North America. Throughout the area these formations, largely limestones, outcrop in the eroded anticlinal valleys, chief of which are Nittany, Kishacoquillas, and Penn's. This area of outcrop is approximately one thousand square miles in extent and comprises portions of seven counties.

The limestone formations dip beneath the late Ordovician and lower Silurian shales and sandstones which form the mountains on the flanks of the northeast-southwest trending

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[1] Abstract of Master's Thesis, Penn State, Feb. 1933.

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valleys. Plate I, copied from a map published by the Pennsylvania State Geological Survey (27) shows approximately the areas underlain by these formations. No attempt is made on this map to show the individual formations separately and the area as mapped includes limestones ranging from Beekmantown to late Trenton age.

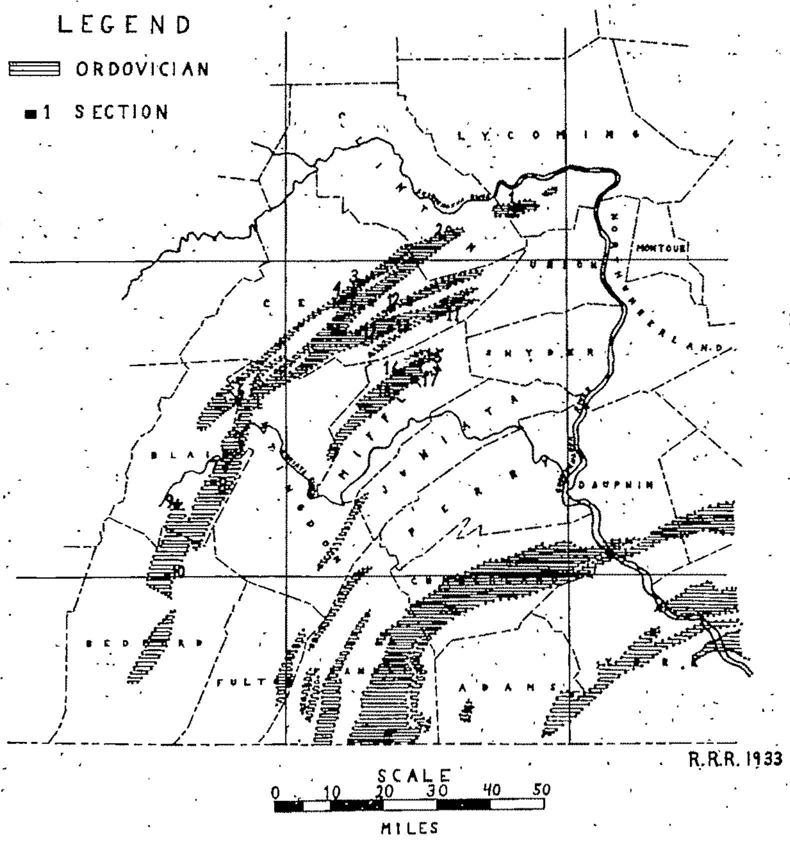

Plate I. Map of central and south central Pennsylvania showing the distribution of the Ordovician formations in the province. The numbers refer to the locations of sections as follows: 1. Nippenose valley, 2. Salona, 3. Bellefonte, 4. Coleville, 5. Pleasant Gap, 6. Union Furnace, 7. Ganister, 8. Royer, 9. Roaring Spring, 10. Loysburg, 11. Coburn, 12. Spring Mills, 13. Center Hill, 14. Lemont, 15. Siglerville, 16. Milroy, 17. Naginey, 18. Reedsville, 19. Oak Hall. Modified after geologic map of Pennsylvania published by the Pennsylvania Geologic Survey.

Good sections while not numerous, are to be found at a number of points. Many of these have been exposed in quarrying operations at various localities, but chiefly, in Nittany Valley.

Field (14) recognizes seven formations of Stones River and Trenton age in the area. They are:

Coburn	Thin, black, shaly limestone with zone of *Camarella hemiplicata at base.*
Salona	Distinguished from superjacent Coburn on faunal grounds.
Rodman	Coarsely crystalline, gray, crinoidal limestone. Closed by a two-foot cobbly zone. Carries *Echinosphaerites aurantium.*
Center Hall	Thin fossiliferous limestones overlying the Valentine wherever that formation is recognized as a lithologic unit.
Valentine	Very pure, 'bird's eye' limestone extensively quarried for use as a flux. Termed Lowville by Butts (12).
Carlim	Dense, bluish, impure limestone characterized by *Tetradium syringoporoides, Girvanella,* and closed by a zone of *Tetradium fibratum.*
Loysburg	Dark, impure, non-fossiliferous, dolomitic limestone characterized by edgewise conglomerates and absence of reef-building organisms.

As used by the author, the base of the Salona is placed from 10 to 12 inches below the horizon used as the base by Whitcomb (46), inasmuch as a marked and persistent change in the lithologic facies occurs at this horizon in most observed sections.

SALONA BENTONITES.

The 6 bentonite beds found near the base of the Salona formation are more persistent and more readily identifiable than the bentonite beds in the older formations. In ascending order they have been designated as beds No. 0, No. 1, No. 2, No. 3, No. 4, and No. 5, respectively. This designation agrees with that used by Whitcomb (45), inasmuch as the additional bentonite recognized by the author is that termed No. 0. Field recognition and identification of the beds have been made only after a consideration of the physical properties of the material; the number of beds in the given formation (recognized on lithologic and faunal grounds); the thickness of the individual beds; the lithology of the immediately adjacent strata; and relationships to any readily recognizable lithologic or faunal zones. Final identification of the individual outcrops as bentonite has been made only after a careful microscopic study of heavy mineral concentrates from the materials in question.

Seventeen sections of the Salona have been visited by the writer and all of these show at least 3 of the 6 bentonite beds. That the remainder have not been discovered is no doubt due to the poor character of the exposures of the formation rather than to the absence of the beds. All six beds have been traced from Roaring Spring in Blair County to Salona in Clinton County, a distance of 80 miles along the strike of the formation; and from Bellefonte to Reedsville, an airline distance of 25 miles at right angles to the strike and across the anticlinal folds of Penn's Valley, Brush Valley, and Kishacoquillas Valley, the actual distance as measured on the surface of the formation as deposited being much greater. In addition, beds No. 1, No. 2, and No. 3 have been traced from Salona to Nippenose Valley, an additional 15 miles along the strike. Beds No. 1, No. 2, No. 3, and No. 5 have been recognized at Loysburg 12 miles southeast of Roaring Spring.

Bentonite bed No. 0 is three-quarters to an inch and a half thick and very persistent. It rests on a 5 to 10-inch bed of typical Salona lithology, which, in turn, rests on the cobbly zone that closes the Rodman. In the Reedsville and nearby sections a zone of black nodular cherts occurs a few inches below this bed.

Bed No. 1 is one inch thick and occurs from 6 to 19 feet above No. 0. Its occurrence within 2 feet of the readily recognizable bed No. 2 makes its identification comparatively easy.

Bentonite bed No. 2 is 5 to 6 inches thick and rests directly upon a one-half to three-inch chert layer which shows a characteristic, checked, iron-stained upper surface. Fragments of *Cryptolithus* are always present on this surface. At no locality is this bed more than 2 feet stratigraphically above bed No. 1. The group of strata consisting of beds No. 1, No. 2, the pronounced chert zone beneath No. 2, and the intervening strata is very readily recognizable and forms a datum plane from which field measurements may be made with confidence.

Bentonite bed No. 3 is from 4 to 10 inches thick and frequently shows considerable increase in thickness due to crushing and mixture with the 8 inches of black shales which overlie it. It has been observed in 13 localities at from 5 to 24 feet above bed No. 2.

Bed No. 4 is 3 to 8 inches thick and is found from 23 to 42 feet above bed No. 3 and approximately 10 feet below the zone of *Homalonotus trentonensis* whose occurrence has been discussed by Whitcomb (47).

Bed No. 5 is 1 to 10 inches thick and has a better development in the more southerly sections. Material from this bed at Union Furnace is the firmest and best preserved bentonite yet discovered in the area. This bed occurs approximately at the top of the zone of *Homalonotus trentonensis.* At no locality has the writer found this fossil at any horizon except between beds No. 4 and No. 5. Whitcomb, who has described this species (47), however, reports it in the beds immediately overlying this bed in the Salona section. Its occurrence there is very rare.[2] It has been observed in 10 sections and has been found loose at 2 other sections. It occurs rather abundantly, being found in the more shaly layers of the formation. The interval between beds No. 4 and No. 5 ranges from a minimum of 30 feet at Salona to a maximum of 107 feet at Union Furnace. In the Union Furnace, Roaring Spring, and Loysburg sections this bed is underlain by a one-inch chert zone similar to that beneath the No. 2 bed.

That other beds of bentonite may exist is quite possible as the poor quality of most of the exposures of the upper Salona would tend to conceal any thin beds. That there is quite probably at least one additional bed is indicated in the Reedsville section. Near the junction of State Highways No. 53 and No. 5 a very prominent horizon of bentonitic material, 10 inches in thickness, outcrops near a concrete abutment in strata whose contained fauna indicate to be of Coburn age. This horizon lies above a concealed interval of approximately 150 feet and is presumably that distance above the next lower bentonite seen, namely, No. 5. It has been found in no other section to date. Why it should appear so prominently at Reedsville and fail in nearby sections is not clear.

A consideration of the thickness of sediment accumulated between successive ash falls at various localities (cf. Plate II) shows clearly that the rate of accumulation varied considerably from locality to locality. As one passes through the Nittany

[2] Personal communication.

Valley area along a northeast-southwest line one finds the strata of the basal Salona increasing in thickness until a maximum is reached in the vicinity of Union Furnace and then

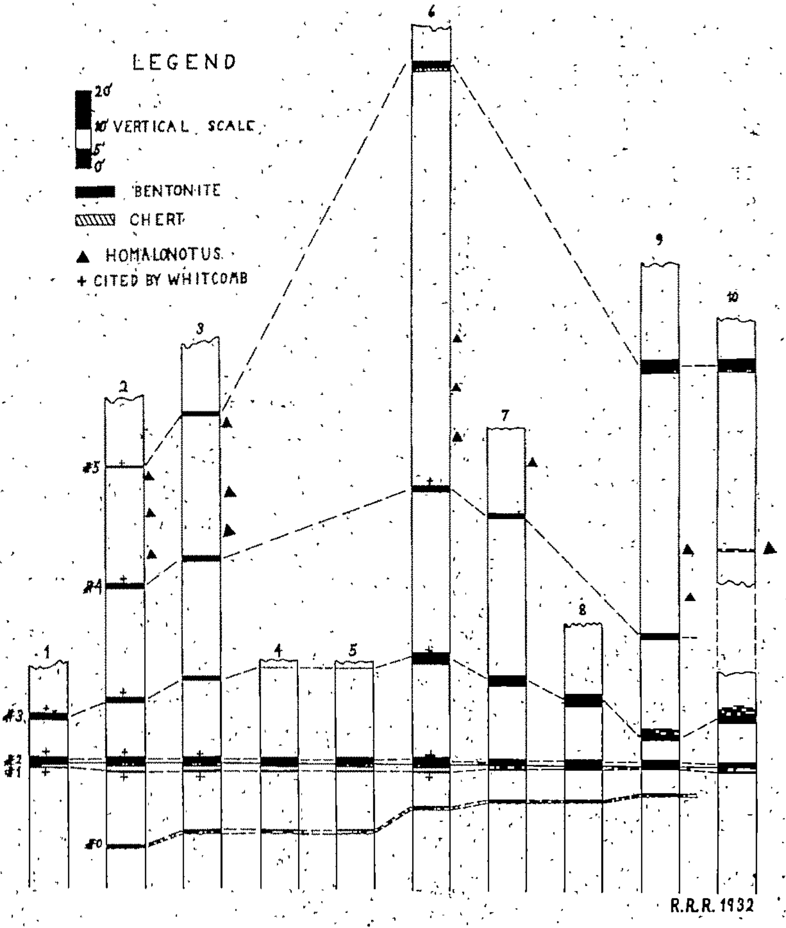

Plate II. Columnar sections showing the stratigraphic position and correlation of the bentonite beds which occur in the base of the Salona formation—Nippenose and Nittany valleys. Localities are the same as in Plate I.

rapidly thinning until in the Roaring Spring section the successive ash falls are separated by but a few feet of strata. It is to be noted that those sections in which accumulation was least rapid, possess, in general, much more shale than such sections as that at Union Furnace. Ulrich (44) has stated that the 'Trenton' of Pennsylvania thins out and disappears from 50 to 75 miles southwest of Bellefonte, this thinning out being due to a barrier in the Paleozoic sea which he has termed the Harrisburg axis. The evidence presented by this thinning of the basal beds of the Salona, which Ulrich termed 'Trenton," agrees in general with this view. However, as one passes from Roaring Spring to the Loysburg section the beds of the basal Salona thicken to the southward—a fact that has been interpreted as indicating that the axis has been crossed or that during early Salona time it did not completely block sedimentation. No section of the basal Salona is available in Pennsylvania to the south of Loysburg. It is thought probable, however, that these same beds may be recognized and traced in northern Virginia and elsewhere.[8]

BENTONITES OF PRE-SALONA AGE.

The recognition and correlation of bentonite beds in this area which are older than the Salona formation have been of particular significance in view of the light which has been shed on the Chazy problem. The exact age and the relationship of the pure 'quarry-rock' of the Salona, Bellefonte, and other sections to the relatively pure 'Carlim' beds extensively quarried at Oak Hall, Naginey, Union Furnace, Ganister, and elsewhere has long been a moot question.

It has been the contention of Field (14) that the pure 'quarry-rock' which he has termed Valentine is but a lens in the upper part of the Carlim formation, and that as one passes eastward and southward these pure beds are replaced by an impure phase indistinguishable from the Carlim and are mapped as such. On faunal grounds he regards the Carlim and hence the Valentine as being of Stones River age.

Butts (11-12) has held that the 'quarry-rock' is of Black River age, is the equivalent of the Bays formation of the Tennessee sections, and has termed this rock Lowville. He considers the upper beds of the Carlim at Lemont and Oak Hall as being equivalent to the Lenoir limestone of the Knoxville, Tennessee, area and applies to them the term 'Lemont Member of the Carlim.' This member he regards as being separated from the 'Lowville' of the Bellefonte section by a hiatus representing the period of deposition of the Holston, Athens, Tellico, and Sevier formations which lie between the Lenoir and the

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[8] Rosenkrans, R. R.: Unpublished MS.

Bays. These formations total 7,500 feet in thickness, hence such a hiatus would represent a considerable break in the sedimentary record. The absence in the Lemont and Oak Hall sections of beds possessing the lithology of the 'quarry-rock' is attributed by Butts to this unconformity.

Inasmuch as beds of bentonite are regarded as sharp time units which furnish accurate datum planes for close stratigraphic correlation, the recognition and correlation of the six older beds in strata that have been variously termed Valentine, Lowville, Carlim, and Lemont Member of the Carlim, offer a clue to the solution of the above taxonomic problem.

The folding which the strata have undergone has tended to squeeze out the thin bentonite beds, so that they are not so persistent as might be desired, and certainly less so than the younger bentonite beds in the Salona formation. Correlation of these older beds has been facilitated by a close consideration of the lithology of the adjacent and intervening strata.

The 6 beds of Pre-Salona age have been designated in descending order as No. A, No. B, No. C, No. D, No. E, and No. F, respectively. Bed No. A occurs approximately 10 feet stratigraphically above the base of the Valentine formation wherever this is recognized as a lithologic unit. It is the thickest and most persistent of the Pre-Salona beds. In the Salona section it is 8 inches in thickness, light gray in color, and talcose. At Bellefonte it is yellow in color, 4 inches in thickness, and overlain by 4 inches of bentonitic shale. In the more southerly sections it thins and finally disappears.

Bed No. B is one-quarter to 2 inches thick and occurs in the Bellefonte section 15 inches below the sharp Valentine-Carlim break which is likewise marked by the mat of *Tetradium fibratum* and *Beatricia gracilis* (?) noted by Field (14). It likewise occupies this position in the Coleville and Pleasant Gap sections. At Salona this bed had been squeezed out, its position being marked by a shaly slickensided zone. In the more southerly sections it has also been recognized.

Approximately 10 feet below bed No. B in the Bellefonte and Pleasant Gap sections is a 1 to 2-inch bed of bentonite that is further characterized by occurring 10 inches above a zone of nodular brown cherts. This same chert zone is present in the Coleville section but the bentonite has been squeezed out. In the section at Lemont a 2-inch bed of bentonite occurs at the base of the 'Lemont Member' and 20 feet below the bed thought to be bentonite No. A. A few inches below this

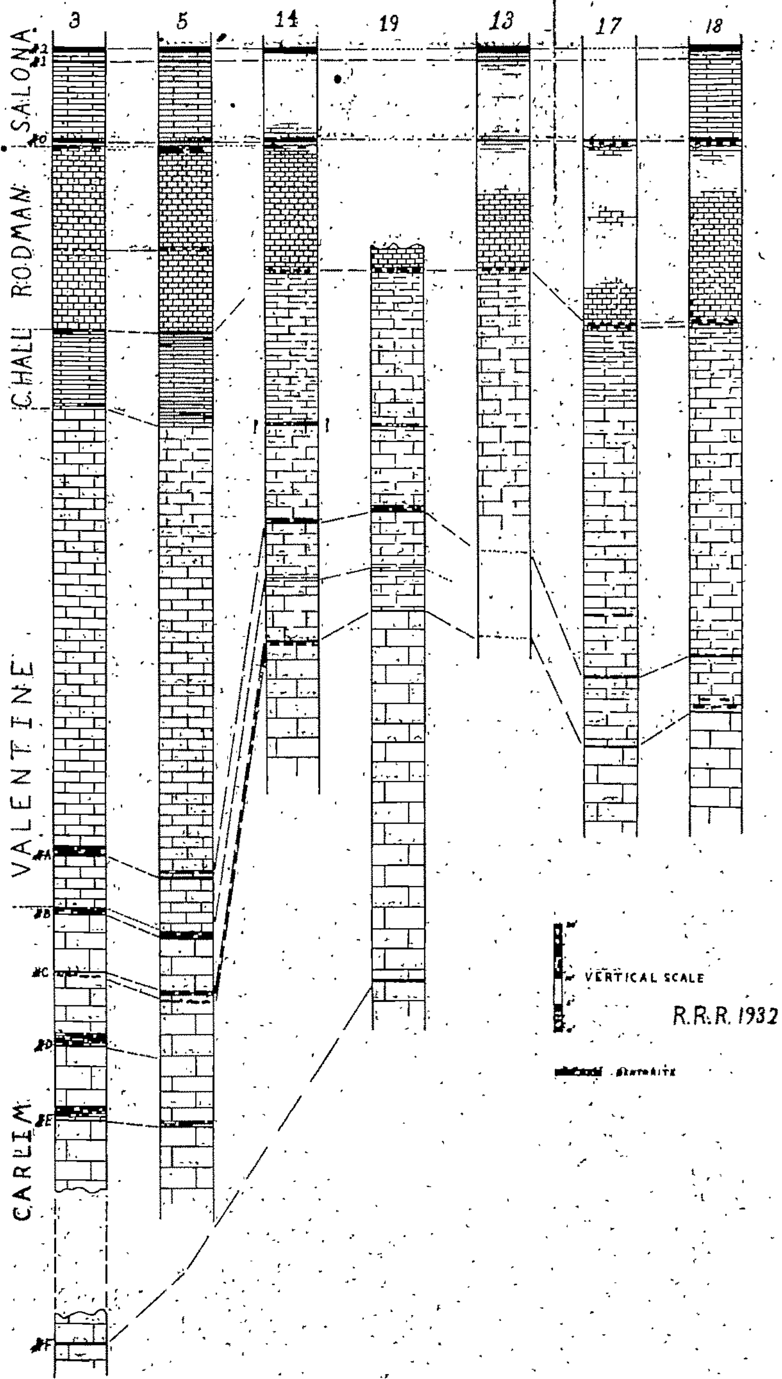

Plate III. Columnar sections showing correlation of the Pre-Salona bentonite beds from Bellefonte to Reedsville. Localities are the same as on Plate I.

bed is the same zone of nodular brov
Pleasant Cap, Coleville, and Bellefonte
regarded as being bed No. C. In streng
a series of thin, impure, somewhat shal
above and these are thought to represe
just above bed No. B in the Bellefont
The Oak Hall section is almost identi
section, with the exception that the two
as No. A and No. C are here only 17 feet
Hill section the interval which would
covered. In the Reedsville and Nagin
found two thin bentonite beds which a
as being beds No. A and No. C.

If this correlation is correct then thes
traced from Bellefonte southeastward tc
ant Gap, Lemont, and Oak Hall and th
conclusions may be drawn (cf. Plate II

1. The interval between the base of the
bentonite bed No. A, or between b
the basal foot of the Salona and bed
nite period of time and the interveni
contemporaneous. At Bellefonte thi
feet and is occupied by strata mappe

   Rodman ....
   Center Hall ....
   Valentine ....

   At Lemont this interval contains 68 f
   23 feet of which are of characteristic
   ing a total of 45 feet as the maxi
   Valentine and Center Hall equivale
   Reedsville the interval measures 92 f
   31 feet are of Rodman lithology. T
   strata represent the Valentine and
   strata, however, are of typical Carlim
   of Field with regard to the replacem
   tine beds in these sections by
   substantiated.
2. The 'Lemont Member of the Carlim,'
Lemont, is shown to be the strict equi
in thickness of strata to the beds at
tonite beds No. A and No. C. Thes
Bellefonte section possess two distinct
10 feet of strata are of such lithology
while the upper 10 feet of strata are

rock' type. One is therefore confronted with the anomalous situation of strata which in the type locality are given a middle Chazy age being the strict equivalent of beds in a nearby section which are termed Lowville by Butts (11-12). The obvious conclusion is that the 'quarry-rock' is not of Black River age, but is the equivalent of beds elsewhere termed Carlim. This conclusion is the same as was reached by Field (14) on paleontological grounds.

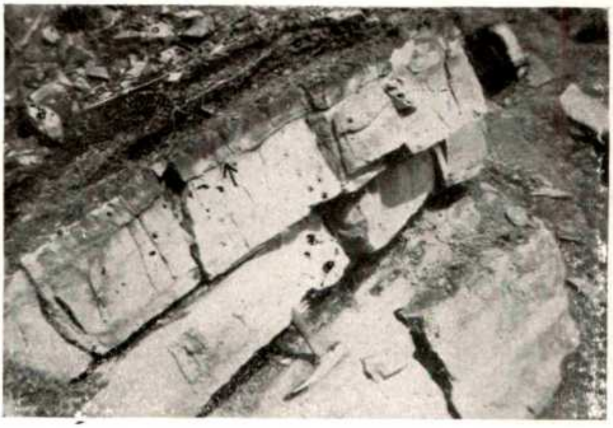

Fig. 2. Outcrop of bentonite beds No. 2 and No. 1 with intervening strata, Bellefonte, Pa. Arrow marks chert zone beneath bed No. 2. Hammer marks bed No. 1.

That the 96 feet of Valentine and Center Hall strata of the Bellefonte section are represented by a maximum of 45 feet of strata in the Lemont (and Oak Hall) sections, and in the Reedsville (and Naginey) by 61 feet of strata is not out of harmony with this conclusion. Lateral variations in rate of sediment accumulation may account for these thicknesses. Removal at the time of the hiatus at the base of the Rodman (Black River) may account for the variation, or a small unconformity within these beds may be the explanation. In support of this latter view it was noted that in the Lemont section 18 feet above the bentonite bed No. A there occurs a 3-inch somewhat sandy limestone bed which appears to rest unconformably upon the subjacent bed. This may represent a minor unconformity within these beds, but certainly there is no marked time break at the base of the Valentine.

In the Bellefonte and Coleville sections two additional 1 to 2-inch bentonite beds occur at horizons 13 and 27 feet below bentonite bed No. C. They have been designated as beds No. D and No. E. Bed No. E has been recognized in the Pleasant Gap section but neither of these thin beds has been noted elsewhere.

A 3 to 6-inch bed of bentonite or bentonitic shale which has been termed bed No. F has been noted at Salona some 60 feet below No. B. At Bellefonte a similar bed is present 50 feet below bed No. E. At Oak Hall a similar bed of very poorly preserved material is present 68 feet below bed No. C. This same zone has been recognized at Union Furnace, and bentonitic material thought to be of the horizon of this bed has been seen at Ganister, Royer, and Roaring Spring. In these southern sections three persistent zones of dark nodular cherts occur in the 10 feet of strata immediately overlying this bed.

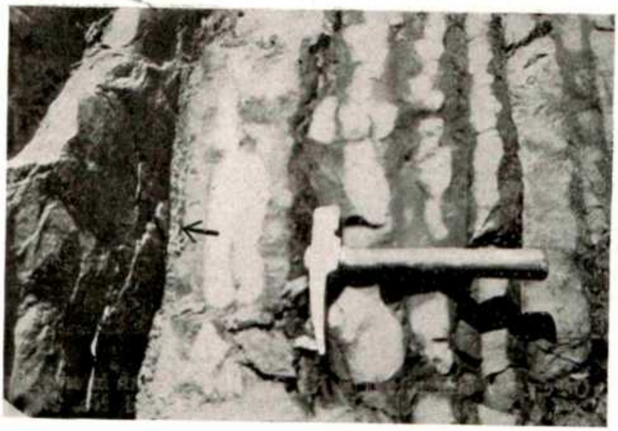

Fig. 3. Salona-Rodman contact, Ganister, Pa. Arrow marks bentonite bed No. 0. Hammer head marks contact and top of two foot cobbly zone that closes the Rodman.

SECTIONS.

The following composite section, which is exposed in and near the quarries of the American Lime and Stone Company at Bellefonte, is fairly typical for the area, though it may be noted that the Valentine facies is not recognized in many sections.

Salona formation		
Impure, shaly, dark limestones. Partly covered		.....
No. 5 bentonite		4 – 6″
Thin-bedded, typical Salona shaly limestones and calcareous shales carrying rather abundant *Homalonotus trentonensis* and *Cryptolithus* in the more shaly layers	26′ ±	
Member similar to overlying but lacking the characteristic *Homalonotus*	10′ ±	
No. 4 bentonite		3 – 6″
Thin-bedded, typical Salona shaly limestones and calcareous shales	30′	
No. 3 bentonite		2 – 3″
Thin-bedded, typical Salona	19′	
Black calcareous shale		6″
No. 2 bentonite		6″
Dark, impure limestone that weathers light gray. Upper 2.5″ to 3″ very black, cherty, and showing characteristically checked, fossiliferous, iron-stained upper surface		11″
Shale parting		.5″
Impure limestone, weathers light gray		6″
Thin, dark gray, calcareous shale		2″
No. 1 bentonite		1 – 2″
Typical Salona limestones	14′	7″
No. 0 bentonite		1″
Typical Salona limestone bed		9″
Rodman formation		
Thin-bedded, coarsely crystalline, impure, crinoidal limestone with thick argillaceous partings and 'cobblestone' appearance when weathered	1′	4″
More or less thin-bedded, coarsely crystalline, light gray limestone. Argillaceous partings show on weathered surfaces	17′	6″
Persistent bed of thin, black, carbonaceous shale		3″
Typical Rodman limestone	14′	9″
Center Hall formation		
Thin-bedded, very fossiliferous, more or less impure, dense, finely crystalline, light gray limestone, resembling the subjacent, massive, pure Valentine strata	14′	4″
Valentine formation		
Massive-bedded, very pure, light gray, dense, 'bird's-eye' limestone. Weathers almost white	81′	2″
Thin, gray, calcareous and bentonitic shale		9.5″
No. A bentonite		4″
Rather massive, typical Valentine limestone	9′	3″
Carlim formation		
Thin-bedded, very dark, shaly, fossiliferous limestone with a mat of *Tetradium fibratum* and *Beatricia gracilis* (?) on its upper surface	1′	3″
No. B bentonite		2″
Massive, rather pure, bluish-gray limestone carrying *Leperditia fabulites* and *Tetradium syringoporoides*	9′	
No. C bentonite		2″
Massive, impure Carlim limestone		8″
Band of black to brown cherts		2″
Massive, impure Carlim limestone	10′	
Very thin, shaly, impure limestone	2′	6″

No. D bentonite		4″
Massive, typical Carlim limestone	10′	9″
Very thin, shaly, impure limestone	2′	4″
No. E bentonite		2″
Massive, impure limestone with abundant *Tetradium syringoporoides*	51′	
No. F bentonitic shale		3″
Typical Carlim limestone	..	.....

PHYSICAL PROPERTIES.

The property of marked sorption of water with accompanying swelling which is characteristic of the western bentonites of Cretaceous and younger age is not present to a great degree in these Ordovician bentonites. When placed in water they disintegrate but do not swell greatly. In color they range from a buff to a creamy yellow if they are slightly weathered, or if fresh they are usually of a light greenish-gray or greenish-yellow color. When wet, the yellowish color is accentuated; when dry, the bentonite is much lighter and usually possesses a waxy luster.

Little or no gritty material is present. The dry weathered material is friable and somewhat earthy. If wet it is more or less plastic. The bentonite from the thicker beds is usually somewhat shaly in appearance, breaking into platy fragments with conchoidal fracture. Approximate specific gravity determinations by the Jolly balance method gave values ranging from 2.40 to 2.55 for many of these materials. It is, of course, recognized that these values are only approximate due to sorption effects when immersed.

CHEMICAL PROPERTIES.

Chemically, these materials resemble one another very closely. In Fig. 1 are presented analyses of apparently fresh, air-dried bentonite that had been crushed to -100 mesh. It is to be noted that they are distinguishable from the younger western bentonites by their consistently higher alkali content and the preponderance of potash over soda. As noted by Honess (17) "the alkalis probably exist partly in chemical combination in the undecomposed feldspars, partly as an essential constituent in the clay-like mineral, and partly as adsorbed salts." The much lower silica content is probably traceable to age and state of alteration. There appears to have been a leaching of silica from the original ash, and the passage of this

Figure 1.

%	1°	2°	3°	4°	5°	6	7	8	9
SiO_2	55.67	48.79	56.03	53.68	57.45	49.40	57.62	54.56	61.13
Fe_2O_3	0.97	5.51	1.82	2.20	1.57	0.74	0.35	0.69	3.52
FeO								1.28	
TiO_2	0.48	0.58	0.55	0.41	0.29	0.44	....	....	0.20
Al_2O_3	23.94	24.24	23.60	23.27	23.14	28.80	24.63	19.97	18.18
CaO	0.34	1.39	0.87	1.23	0.50	0.74	4.03	1.08	1.62
MgO	4.16	4.09	2.72	3.00	2.82	3.80	0.32	5.08	2.29
Na_2O	1.56	1.26	1.63	1.24	1.35	1.68	3.15	1.66	1.86
K_2O	4.55	4.30	4.98	4.99	5.68	4.98	2.97	4.06	0.67
P_2O_5	0.14	0.20	0.18	0.14	0.31	0.13	...	0.15	....
Loss above 110°	6.42	7.53	5.79	6.05	5.44	6.13	6.88	5.32	10.37
H_2O at 110°	1.85	2.56	2.40	4.85	1.90	3.02	....	6.62	....
F	....	....	....	....	....	....	....	0.13	....
SO_3	0.57	....	....	....	....	0.79	....	....	....
Total	100.65	100.45	100.57	101.06	100.45	100.65	99.95	100.60	99.84

1* Av. 4 analyses of bed No. 2 from Salona, Pa.
2* Av. 4 analyses of bed No. 2 from Bellefonte, Pa.
3* Av. 4 analyses of bed No. 2 from Union Furnace, Pa.
4* Av. 4 analyses of bed No. 2 from Roaring Spring, Pa.
5* Av. 4 analyses of bed No. 5 from Union Furnace, Pa.
* Analyses by G. Brady, Penna. State Col. Min. Ind. Exper. Sta.
6 Bed No. C from Oak Hall, Pa., T. W. Mason analyst, cf. (17).
7 Composite analyses of material from Rockbridge County, Va. Analyst Dr. L. E. Porter, cf. Jour. Geol., Vol. 35, No. 6, p. 539, No. 3, Aug.-Sept. 1927.
8 Material from High Bridge, Ky. Analyst D. F. Farar. cf. Nelson, W. A.: Volcanic Ash Bed in the Ord. of Tenn., Ky., and Ala., Bull. G. S. A., Vol. 33, No. 2, p. 614, 1922.
9 Av. 14 analyses. 11 by Spence and 3 by Wherry. cf. Hugh S. Spence; Bentonite, Can. Dept. Mines, No. 626, Nos. 4-5-7-8-9-10, first table p. 14, and Nos. 1-2-4-5-6, second table, p. 14. See also Nelson, W. A.: Volcanic Ash Bed in the Ord. of Tenn., Ky., and Ala., Bull. G. S. A., Vol. 33, No. 2, Nos. 5-6-7 on p. 614. These analyses are all of Cretaceous or younger bentonites, 1924, 1922.

silica into the subjacent strata probably explains the presence of a silicified or cherty layer frequently noted beneath the thicker bentonite beds.

PETROGRAPHY.

A petrographic study has been made of the freshest material obtainable from each outcrop. The object of this study has been two-fold, i.e.:

1. The establishment of the volcanic origin of the material in question.
2. The discovery of any distinctive petrographic characteristics of the individual beds which would make possible their identification upon petrographic grounds alone.

Two methods of attack have been utilized. The first, a study of thin sections, emphasizes texture and those structures which have been inherited from the ash from which the bentonite was derived. A number of thin sections have been studied. All have showed somewhat similar texture and composition. The 'bogen' structure characteristic of such volcanic materials seems to be so extremely fine that it has not been recognized, though the curved outlines of some of the feldspar fragments suggest this sort of texture. Beyond the possible recognition of material from bed No. 4 by its seemingly much greater abundance of biotite fragments, no individual bed possesses outstanding diagnostic properties.

The second method of petrographic study which has been used is that of examination of heavy residue concentrates. This method lends itself to the quick and economical determination of the bentonitic character of these materials and has been employed very successfully. Residues were prepared from each of the outcrops discovered, the following treatment being employed:

> Fresh, air-dried samples of the material to be examined were crushed to -80 mesh. Approximately 50 gms. of this material were placed in a large beaker, half a liter of water added, and then boiled vigorously for two hours. It was found that violent boiling aided in the breakdown of the matrix material and tended to set free the heavy mineral grains. At the end of this period the finer and lighter particles were decanted, more water added, and the material violently agitated. After fifteen seconds settling the supernatant liquid was decanted and the procedure repeated until a clean residue was obtained. This treatment served to concentrate those heavy mineral grains present in the material, but whose presence was not always noted in thin sections, thus affording opportunity for their study and identification by immersion methods. Only qualitative data were obtained. Attempts at quantitative data showed that this treatment measured only the exent to which the matrix was being broken down, or had been broken down by weathering, and the results were not comparable.

In some cases the residue obtained in this manner was further separated by means of bromoform. To effect a complete separation of the heavy mineral grains it was found necessary to centrifuge the material according to the method of Jeffries (18).

The mineral species noted in the residues are not numerous and many of those observed are of a secondary nature. Those noted are: biotite, zircon, apatite, fluorite, feldspar, calcite, pyrite, limonite, gypsum, occasional quartz, and the clay-mineral which makes up much of the bentonite and is probably montmorillonite (?) (36).

Of these, gypsum, which has been seen in only one residue, pyrite, limonite (both granular and pseudomorph after pyrite), and the purple fluorite seen in some of the residues are regarded as secondary. Calcite is looked upon as being either secondary or the result of mechanical contamination of the sample. Only an occasional detrital grain of quartz has been noted, most of the residues showing none, and in the single case of the sixth bed at Lemont a few authigenic quartz crystals have been seen.

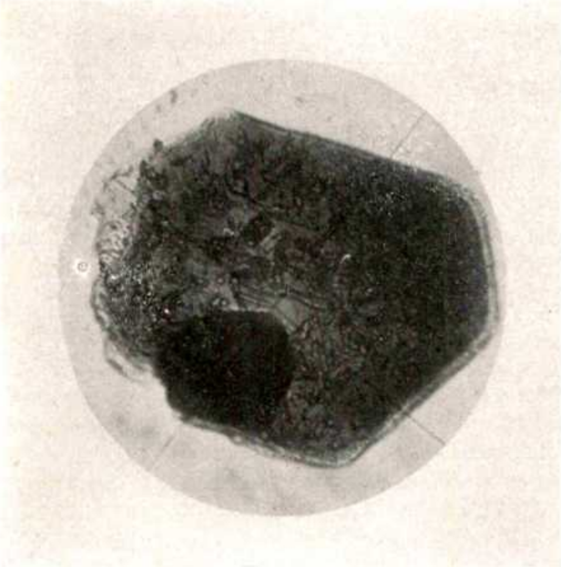

Fig. 4. Biotite from bed No. 4, at Roaring Spring. Note rod-like inclusions.

Every residue examined contains more or less euhedral zircon and apatite and in many cases it is possible to determine the crystal forms on the zircon. In size the zircons range from .3 mm. in length downward, the average observed being about .2 mm. Some zircons contain rod-like inclusions.

Fresh flakes of biotite, unaltered, often hexagonal in outline and frequently crowded with interlacing rod-like inclusions (cf. Fig. 4), have been seen in all of the residues obtained from those beds which occur in the Salona formation. As pointed out by Honess (17) this biotite may be regarded as diagnostic of volcanic origin. The individual flakes are often of a reddish-brown color though some are lighter and more nearly straw-colored. Probably the color variations observed are due to leaching or to incipient alteration. It is well known that biotite is relatively unstable and alters to chlorite. Many thin sections of the bentonite show that the biotite which they contain is more or less altered. Biotite flakes from the No. 4 bed at Roaring Spring frequently show pyritohedra of pyrite attached to their surfaces.

As a general rule, the residues from the Union Furnace, Ganister, and Roaring Spring sections yield the greatest abundance of biotite. Beds No. 4 and No. 5 are particularly noteworthy in this respect. Counts on the heavy residue after a bromoform separation of material from bed No. 5 at Roaring Spring show: biotite 82%, pyrite 8%, apatite 6%, and zircon 4%. None of the Pre-Salona bentonites other than bed No. A have yielded any biotite, a fact which may be attributed either to destruction by alteration or to original absence.

The clay-mineral which makes up a large portion of these bentonites is very finely divided. Under high magnification it is seen to be somewhat micaceous in habit, though in thin sections it appears to be finely fibrous.

The material from bed No. A at Salona is unique in that it seems to be composed almost entirely of a clay-mineral with optical properties suggesting kaolinite. Physically, the material from this bed is a shaly-appearing, greenish-gray bentonite which does not disintegrate very rapidly when placed in water. The material has a pronounced acid taste and is found to contain abundant minute cubes of fresh pyrite. That the material is bentonite is shown by its stratigraphic position and by the presence of the characteristic euhedral accessories, with the absence of quartz. The clay-mineral which comprises approximately 75% of this bed appears to be an aggregate, does not show complete extinction, but yields excellent interference figures. Optic axis figures are most frequently seen, though acute bisectrix figures are not rare. The sign is negative. The indices of refraction, as determined by the oil immersion method, are $X = 1.559$, $Y = 1.564$, and $Z = 1.565$. $2V$ is small but variable.

CORRELATION WITH OTHER AREAS.

To attempt, with our present knowledge of the distribution of Ordovician bentonites in the eastern United States, a sweeping correlation throughout so large an area would be folly. With 12 beds recognized in the central Pennsylvania province, several beds reported from Tennessee and others from various states, such a correlation at present would be meaningless. It is not possible, at present, to say which of the 12, if any, is the same as a bed seen in Tennessee or Iowa. It has been the purpose of this paper only to correlate and map all of the bentonite beds within a small province. It is hoped that this type of detailed work may be carried on in neighboring provinces with the possibility of eventually tying in the beds of the various areas. Work of this character in Virginia and elsewhere has been undertaken by the author and when completed should lead to a much clearer view of middle Ordovician stratigraphy.

SUMMARY.

Studies of the central Pennsylvania bentonite occurrences have been carried out with the following results:

1. A large number of previously unreported outcrops have been discovered.
2. Six beds of bentonite occurring in the basal portion of the Salona formation have been recognized, their bentonitic character established, and they have been traced throughout an area more than 110 miles long and 25 miles wide.
3. The base of the Salona formation has been shown to be at the top of a 2-foot cobbly zone and from 5 to 10 inches below the persistent bentonite bed No. 0.
4. Information relative to the rate of sediment accumulation within the province in early Salona time has been presented. It has been shown that the beds of the basal Salona thin to the southward, the maximum thinning occurring near Roaring Spring, thus coinciding with the Harrisburg axis concept of Ulrich (44).
5. The view of Field that the Valentine formation is but a lens in the upper Carlim replaced to the southeast by an impure phase mapped as Carlim has been largely substantiated.
6. Data have been presented which point to the conclusion that the 'Lemont Member of the Carlim' of the type section is in part equivalent to beds which Butts (who proposed this

term) has mapped as being much younger in age. This interpretation of the data indicates that the supposed hiatus, equivalent to several thousand feet of sediments, which has been said to exist at the base of the 'quarry-rock' of the Bellefonte section is not present.

7. Six beds of bentonite of Pre-Salona age have been recognized and correlated throughout a portion of the area.

8. The essential contemporaneity of the strata quarried for flux at Ganister, Naginey, and Union Furnace with the pure 'quarry-rock' of the Bellefonte section has been established.

9. It has been shown that there are apparently no diagnostic differences in the character of the bentonites in the 12 beds studied.

10. Detailed columnar sections of the middle Ordovician limestones have been measured and the close correlation of these formations has established a basis upon which future stratigraphic studies, particularly those based on the study of insoluble residues, may be carried out.

11. The detailed mapping and correlation of the bentonite beds of this province have given a basis upon which further work may be and is being carried on in the study and correlation of the Ordovician bentonite beds of neighboring provinces. It is hoped that these studies may be extended to the point where a correlation of these beds with those reported elsewhere in eastern North America may be made with confidence.[4]

[4] The writer wishes to gratefully acknowledge the kindness of Dr. W. H. Twenhofel who has read the manuscript of this paper, and to express his appreciation for the guidance and inspiration of Dr. A. P. Honess, under whose direction this paper has been prepared.

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NEPHELINE SYENITE FROM SOLWEZI, NORTHERN RHODESIA.

FRANK D. ADAMS AND F. FITZ OSBORNE.

INTRODUCTION.

The extended geological surveys which are being carried out in Northern Rhodesia have produced not only very valuable economic results but also have yielded interesting material and data of purely scientific concern.

Two years ago the writers received from Dr. J. Austen Bancroft, Consulting Geologist of the British South Africa Company, two specimens of nepheline syenite from widely-separated localities in Northern Rhodesia. They described them in a paper that appeared in the Canadian Journal of Research.[1]

As these rocks presented a number of features of marked interest, especially those from a locality about 40 miles west of Solwezi, a request for additional specimens was made to Dr. Bancroft. These having been received and examined, the present paper has been prepared setting forth the results of the examination of the whole collection. This consists of eleven specimens of nepheline syenite, two of scapolite amphibolite, and one of quartz-mica schist. Sixty thin sections and sixteen polished surfaces were examined, and a chemical analysis of one specimen of nepheline syenite was made.

The specimens are from a locality about 40 miles west of Solwezi and a short distance south of the boundary between Northern Rhodesia and the Belgian Congo. Solwezi is about 80 miles west of Elizabethville.

The examination of these specimens gives the following results:

Mica schist. The mica schist shows a contorted schistose structure and is thoroughly impregnated with brown iron oxides. Quartz and muscovite are the only primary minerals, but both have been stained and partially replaced by iron oxides.

Scapolite amphibolite. The two specimens of scapolite amphibolite resemble theralites megascopically, and by one acquainted with the theralitic rocks of the Monteregian province, might be mistaken for them. Both hand specimens

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[1] Adams, F. D., and Osborne, F. F. "On two nepheline-sodalite-syenites from new localities in Northern Rhodesia," Can. Jour. Research 6, pp. 571-576, 1932.

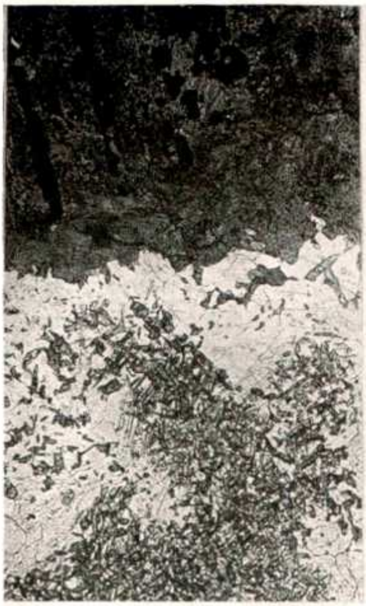

FIG. 1.

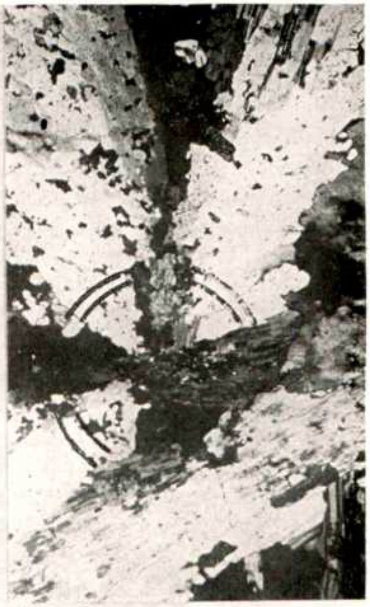

FIG. 2.

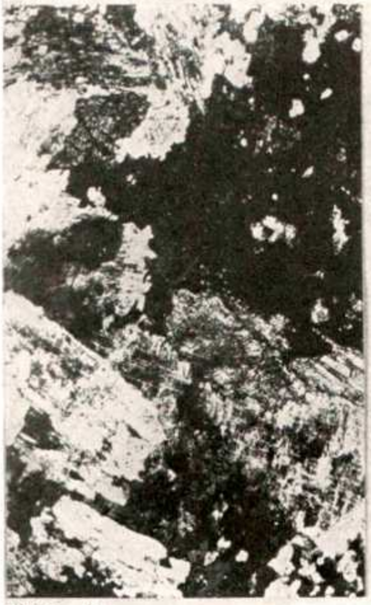

FIG. 3.

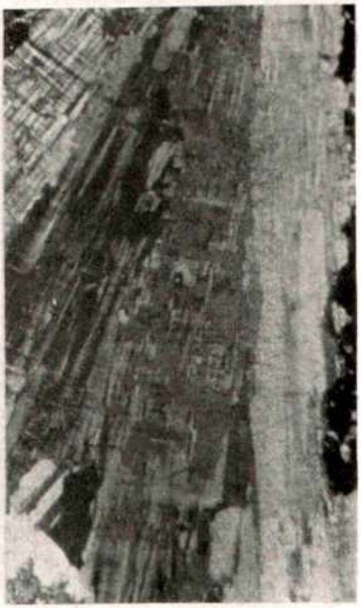

FIG. 4.

Fig. 1. Scapolite amphibolite, one nicol, x 23. Hornblende aggregate with rutile (black) in contact with quartz and scapolite containing small crystals of zoisite.

Fig. 2. Nepheline syenite, crossed nicols, x 23. Rosette of albite in contact with a crystal of microcline (at bottom). The albite shows Brewster's cross.

Fig. 3. Texture of normal nepheline syenite, crossed nicols, x 23. Microcline and albite. Black is aluminous aegirine and garnet.

Fig. 4. Nepheline syenite, crossed nicols, x 23. Somewhat diverging aggregate of microcline being replaced by microcline.

show about 60 per cent of dark minerals in a medium-grained aggregate with light minerals. The structure is granitic and without visible foliation.

The microscope shows, in order of abundance, hornblende, dipyre, quartz, zoisite, biotite, rutile, apatite, garnet, and opaque ores. Hornblende forms about 55 per cent of one specimen. Its pleochroism is less intense than that of most amphiboles occurring in amphibolites. The absorption is $\alpha =$ pale green, $\beta =$ pale blue-green, and $\gamma =$ pale blue-green. The extinction angle, $\gamma \wedge c$, is 18°. The irregular and fibrous aggregates of hornblende contain minute inclusions of the light-coloured minerals of the rock and appear to have replaced a mineral that was somewat ophitic toward plagioclase (now quartz and dipyre). In one specimen the pale amphibole is surrounded by a variety that is more intensely absorptive and whose extinction angle is 23°. This variety is probably somewhat sodic.

Dipyre forms about 25 per cent of the rock. It is in irregular aggregates, which show a strain extinction and interlocking sutures between adjacent grains of the same mineral. In a few slides myrmekite-like intergrowths (symplektite) of the dipyre and quartz are seen. The rods of quartz form about 5 per cent of the aggregate. The dipyre was identified by its ϵ, which is lower than the ω of quartz.

Quartz forms about 10 per cent of the rock and is commonly in grains of the same order of size as those of scapolite but is interposed between the scapolite and the hornblende. Inclusions of zoisite, such as those found in the scapolite, are lacking. Biotite forms about 3 per cent of the rock and is associated with the hornblende.

Part of the dipyre is filled with crystals of zoisite about .04 mm. long (see Fig. 1). They form a felted aggregate, which may occupy more than a quarter of the bulk of the scapolite. The zoisite shows the characteristic anomalous interference colour and both positive and negative elongation indicating that the optic-axial plane is transverse to the elongation.

The accessory minerals are present in small amount only. One grain of epidote associated with hornblende, several crystals of apatite, and some garnet were noted. Rutile is found in characteristic skeleton shapes in the hornblende. Minute grains of zircon in the hornblende are surrounded by radioactive halos.

Origin of the scapolite amphibolite. The absence of linear structures in the rock suggests that shearing stresses were not active during its formation. The texture indicates that the rock is derived from a coarse-grained rock such as a gabbro. The amphibole and rutile have taken the place of pyroxene, and the dipyre and zoisite represent plagioclase. The quartz may have been in part released during the change from augite to hornblende or introduced with the chlorine-bearing solutions that brought about the metamorphism.

The rock is essentially an amphibolite in which the plagioclase has been completely replaced by dipyre and zoisite and may be the result of the contact action of the nepheline syenite on a gabbro. It resembles the scapolite amphibolite developed from the gabbro of Glamorgan, Ontario,[2] near the contact with nepheline syenite. It is similar to many occurrences of amphibolite except that the feldspar is replaced by dipyre and zoisite, whose occurrence was probably determined by the chlorine available from nepheline-syenite magma.

NEPHELINE SYENITES.

Hand specimens. The nepheline syenites from near Solwezi are all rocks of medium granularity. Several of the specimens were taken from the outcrop and show the pitted surfaces from which the feldspathoids have been removed by weathering. The feldspars stand out above the surface and show more or less idiomorphic outline. A pale-green fibrous pyroxene is found in most specimens. Muscovite is found in two.

In most specimens the feldspars are white and show a simple twinning. The most distinctive variation is in the appearance of the feldspathoids of the rocks. Some varieties show only a grey nepheline, others show a pale-blue nepheline associated with a more deeply-coloured sodalite and a honey-yellow cancrinite. The red aggregate known as *spreustein* or hydronephelite replaces part of the nepheline and sodalite of some of the rocks, and the feldspar may be coloured red. The specimens rich in muscovite are red.

The appearance of the rocks in hand specimens leaves little doubt that they are co-magmatic although they range from grey varieties relieved only by green pyroxenes, to deep red varieties. The surfaces of the varieties with blue sodalite and green pyroxene with white feldspar have a very striking appearance.

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[2] Adams, F. D., and Barlow, A. E. Geology of the Haliburton and Bancroft areas, Geological Survey of Canada, Memoir 6, 154, 1910.

Microscopic Character.

The thin sections of the rocks show interesting textures unlike most of those found in the well-known nepheline syenites of North America.

Feldspars. All the thin sections have two feldspars: in most the microcline exceeds albite in amount, but in a few the albite is in excess of the microcline. The microcline shows the characteristic quadrille twinning as well as twinning after the Carlsbad law. It has a greater tendency toward idiomorphism than any other principal constituent of the rock and shows, in some specimens, a poorly-defined radiating structure, but most commonly the laths tend to have a parallel arrangement. See Fig. 3. In most of the slides the microcline has a brownish colour in transmitted light, owing to a very fine and uniformly-distributed alteration product. In some specimens the margins of the grains are clear.

Most of the albite appears to have replaced microcline. In places the two feldspars show a nearly parallel intergrowth but in others the albite tends to be more radiating in habit than the microcline. The albite is lamellar and resembles, on the microscopic scale, the cleavelandite found in pegmatite dikes. A few rosettes of the radiating albite, showing Brewster's cross (see Fig. 2), were noted, and the blades cut across microcline of diverse orientations. The replacement of the microcline appears to start about the margins of the grains and along the Carlsbad twinning junctures. In some specimens only a few anhedra of microcline in parallel orientation enclosed within albite mark larger crystals of this mineral which have been almost completely replaced by albite. The albite itself is not invariably twinned, this is especially the case in the larger crystals.

The specimens with most pyroxene show the lower content of feldspathoids and albite. The specimens with muscovite show a considerable amount of albite and feldspathoids.

Feldspathoids. Nepheline and other feldspathoids are found in every slide, and they are invariably interstitial to the feldspars. Most of the nepheline is water-clear but some is extensively altered. Granular sodalite may be formed from it along the margins of the grains. In places the structure suggests that nepheline replaces microcline: the nepheline contains minute anhedra of the microcline, which have the same orientation as adjacent grains of microcline. Elsewhere sodalite appears in the same relationship and appears to have included nepheline as well as microcline. In some thin sections the nepheline is altered to a plumose aggregate with the optical properties of hydronephelite, and in other places laths of cancrinite are developed in the nepheline. Some nepheline is replaced by a fine-grained cloudy aggregate resembling natrolite. An unidentified mineral of zeolitic appearance but showing a very fine polysynthetic twinning is also found.

One specimen shows scapolite which is distinguished from cancrinite by its indices of refraction, which are higher than those of microcline. It was noted in only one thin section and was associated with feldspathoids. Scapolite is a primary constituent of some nepheline syenites of the Haliburton-Bancroft area.

Pyroxene. The pyroxene is found as fibrous aggregates of slender crystals, as irregular clots, and as disseminated grains. The mineral is practically colourless in thin section and at first sight resembles enstatite. It has a noticeable pleochroism in yellow tints where it is contact with grains of perovskite. The lowest index of refraction as determined by immersion in oil is 1.72, and γ-α estimated in thin section from a grain showing central emergence of β is .03. The extinction angle, $\alpha \wedge c$ is 7°, and the mineral is optically negative with an optic-axial angle of about 65°. The dispersion of the optic axis is $\rho > v$ and is so strong that the extinction is incomplete in white light.

The chemical analysis of a specimen with 14% pyroxene showed a very low content of divalent bases, and pyroxene is probably low in them. The analysis shows a considerable excess of Al_2O_3 over the amount necessary to form feldspar and feldspathoid. The excess is probably present as jadeite molecule in the pyroxene. The pyroxene has the extinction angle and appearance of acmite, but the birefringence is about one half, and the index is .05 below the values for aegirine. The mineral is probably an aluminous or jadeitic aegirine.

An isotropic garnet is found with the aluminous aegirine. It resembles the pyroxene very closely in index but lacks the perfect cleavage. Parts of the mineral are pale yellow in colour, but they grade into colourless portions. In all the specimens garnet is found closely associated with the pyroxene.

It is pale brown in the hand specimens of the rock and is probably grossularite.

Muscovite. Two of the specimens of nepheline syenite contain muscovite. The muscovite forms clots composed of several plates which have the appearance of starting to crystallize about a nucleus of other minerals. The mica is not found with pyroxene in any of the thin sections unless some very small grains are remnants of pyroxene in the process of alteration. The two specimens with muscovite are also the richest in albite, and the muscovite in part appears to have replaced feldspathoids between the grains of albite.

Accessory minerals. The accessory minerals are present in small amounts. In one specimen perovskite occurs in small grains that show a transition in colour from red to colourless from the core outward. Zircon is found in scattered grains, and apatite was noted in one or two slides. A uniaxial carbonate, probably iron-bearing, forms as much as two per cent of some of the rocks. Magnetite and hematite are found in every rock. The magnetite is related in occurrence to the feldspathoids, being found in the interstices between feldspar and pyroxene. The hematite is an alteration product of the magnetite. It forms as a mantle around grains of magnetite and as blades along the octahedral partings within it. Ilmenite and sulphides are lacking.

The accessory minerals are sparsely and erratically distributed. Several minerals were found in only one or two grains that did not afford sufficient data for their determination. For example, fifteen thin sections of the rock, whose chemical analysis is given below, were prepared. In these, two grains of a mineral of high birefringence, high indices, large optic axial angle, negative sign, and 45° extinction were found. The mineral could not be identified from these data. One of the muscovite-bearing rocks has a few grains of a pale-green mineral resembling chlorite.

A bromoform separation of a pound of the rock should yield an interesting and varied collection of heavy minerals, but there was not enough material available for such a test after the preparation of thin sections and the polished surfaces.

Distribution of the minerals in the rocks. Microcline is found in greatest abundance in specimens rich in aluminous aegirine, and muscovite is found in the specimens rich in albite. The alteration of nepheline appears to be unrelated to the content of aegirine, but the most intensive alteration to spreustein is found in the rocks rich in muscovite. All the varieties show a texture in which the feldspars are idiomorphic toward the pyroxene, but both minerals are euhedral toward the feldspathoids, which commonly occupy the triangular spaces between the laths of feldspar.

Chemical Composition.

An average specimen of the nepheline syenite containing aluminous aegirine was chosen for analysis. The results of the analysis with that of two other rocks is given in Table I.

TABLE I.

	I	II	III
SiO_2	56.31	57.87	56.74
TiO_2	tr.	.48	.40
Al_2O_3	19.89	18.46	19.32
Fe_2O_3	4.28	4.63	2.37
FeO	.29	.40	1.65
MnO	.16	....	.07
MgO	.26	.61	.27
CaO	.74	1.03	1.98
Na_2O	8.33	8.83	8.05
K_2O	5.75	5.74	5.88
H_2O+	.68	.90	1.12
H_2O-	.13	.70	.32
CO_2	1.27	....	1.50
P_2O_5	n.d	.14	.03
ZrO_2	.16	....	.02
SO_3	.19	nil	.12
Cl	1.13	.62	....
BaO	tr.	....	.16
	99.57	100.41	100.17

I. Sodalite-nepheline syenite, Solwezi. Analyst, Mary G. Keyes.
II. Phonolite, Patagwa River, near Utanjilva, Nyassa.[3] Analyst, Eyme.
III. Cancinite syenite, Beaver Creek, Uncompaghre Quadrangle, Col.,[4] with SrO .12 and S .05. Analyst, G. Steiger.

[3] Lehmann, E. Das Vulkangebiet am Nordende des Nyassa als magmatische Provinz., Zeitschr. f. Vulkanologie, Erganzb. IV, p. 107, 1924.
[4] Washington, H. S. Washington's Tables, p. 295, No. 13.

The mode of the analysed specimen (in weight per cent) is as follows: microcline and albite, 52%; sodalite, 21%; pyroxene, 14%; nepheline, 11%; and accessory minerals, 2%. The norm of the specimen calculated from the above analysis is: orthoclase, 34.47%; albite, 47.68%; nepheline, 2.27%; corundum, 3.47%; halite, 1.76%; thenardite, .28%; sodium carbonate, 1.38%; zircon, .18%; olivine, .46%; magnetite, .93%; hematite, 3.68%; and calcite, 1.30%. The divergence between the mode and the norm is very striking and illustrates again one of the weaknesses of the normative system of classification.

In Table I the analysis which resembles most closely that of the rock from Solwezi is another African rock, a phonolite, listed as II. It is from a locality about 500 miles from Solwezi and is an effusive rock described by Lehmann.[6] The calculated "mode" is: feldspar, 67.84%; feldspathoid, 14.84%; aegirine-augite, 17.19%; ores, .26%; titanite, .18%; and apatite, .28%. This phonolite is one of the Tertiary flows, and the similarity of the two analyses suggests that the nepheline syenite (I) may be part of the same magma province as the phonolite (II). The similarity in composition, however, is only suggestive. The age of both rocks is uncertain: the Solwezi rocks are known to be younger than the Muschinga schists.

Genesis of the Rocks.

The data available as yet for the determination of the origin of these rocks are restricted to what may be gained from a study of the specimens themselves, inasmuch as the mode of occurrence in the field is unknown to the writers. The similarity of the rock analysed, which is an average type, to the phonolite of Lake Nyassa indicates the existence of a magma having the composition of the nepheline syenites, if such evidence is necessary.

The rock started to crystallize with the separation of microcline (probably at that time orthoclase). The aegirine started soon after, for minute crystals of the aegirine are included in the microcline. The growth of the aegirine was slower than that of the microcline. The microcline was then replaced by albite. The crystals of microcline show rude alignment, probably a result of the flow of the magma during its emplacement, but this alignment is not shared by the albite, except insofar as it is in parallel growth with some microcline. The rock must have been crystalline to such an extent as to inhibit movement to allow the albite to develop as rosettes at the expense of microcline. The albite also form elongated and lamellar groups, which cut across the structure of the microcline. The feldspathoids, with a little microcline and aegirine, appear to have crystallized in the interstices between the crystals of microcline. Albite appears to have been developed only rarely in the interstices.

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[6] Lehmann, op. cit., pp. 41-42 and p. 107.

At a later stage muscovite crystallized instead of aegirine. The rock containing muscovite underwent a more extensive "albitization" than did the aegirine-rich varieties. The muscovite appears to have developed in the interspaces between the laths of feldspar to a greater extent than did the aegirine.

These rocks afford a particularly interesting example of the formation of minerals of unusual composition due to the abnormal composition of the magma. If the content of alkalies had been only slightly lower, corundum would have appeared. The excess silica that is in the jadeite molecule would have combined with some of the feldspathoid to make albite. It may be expected that corundum will be found in association with the rocks of this series. The increasing content of water and the excess of alumina with the presence of microcline may account for the formation of the muscovite. The formation of muscovite from orthoclase in the presence of water and corundum has been described by Adams and Barlow,[6] who gave the following equation:

$$KAlSi_3O_8 + Al_2O_3 + H_2O = KH_2Al_3(SiO_4)_3$$

It is probable that it was alumina made available by the breaking up of the aegirine which allowed the muscovite to form. The sodium so released may have escaped with the volatile constituents and been responsible for the formation of the sodic scapolite in the amphibolite.

Conditions of consolidation. The extensive replacement of the microcline by albite suggests that the cooling must have been slow. The elongated and radiating structure of the albite and its resemblance to the lamellar cleavelandite of pegmatite dikes suggests a similarity of origin. The transgressive rosettes suggest replacement. Such a replacement must have taken place after the rock was nearly rigid, otherwise a slight movement would have made the secondary albite granular rather than lamellar. The resulting texture is quite dissimilar to that of any of the nepheline syenites known to the authors, in that in them there is little evidence of such thorough replacement.

Nepheline syenite of Loangwa River. The authors have also received from Dr. Bancroft a specimen of a nepheline-sodalite-cancrinite syenite from Loangwa River near the border of Northern Rhodesia and Nyassaland. This is about 500 miles from the Solwezi locality, but the two rocks have characters in common.

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[6] Adams, F. D., and Barlow, A. E., op. cit., p. 249.

The rock from Loangwa is coarse in grain and composed of the same essential minerals as those from Solwezi except that biotite is found instead of muscovite. The microcline is mauve in hand specimens but water-clear in thin sections. It shows Carlsbad twinning as well as the moiré twinning and is replaced along irregular lines by albite. The structure is much more irregular than the microperthite that is attributed to the unmixing of a solid solution. The nepheline is in clear grains but is replaced along the margins by sodalite, cancrinite, and natrolite. An aluminous aegirine, optically similar to that from Solwezi, is found with biotite. The biotite surrounds the pyroxene in some places, but in most places the biotite is separated from the pyroxene by a rim of feldspar.

The accessory minerals are zircon, calcite, magnetite, hematite, ilmenite, pyrite, and chalcopyrite. It is to be noted that ilmenite and iron sulphides are wanting at Solwezi.

The petrographical province. The two nepheline syenites are probably part of the same petrographical province and may be a plutonic facies of the effusive rocks at the north end of Lake Nyassa. The plutonic equivalents of the trachyandesites of the volcanic district have not been studied. The plutonic rocks appear to have crystallized slowly and without much deformation, thus allowing the pronounced replacement structures to be developed.

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DISCUSSION AND COMMUNICATIONS.

CUMULATIVE CURVES AND HISTOGRAMS.

In the November number of this Journal E. Wayne Galliher has set forth the advantages of cumulative curves over histograms in the representation of mechanical composition of sediments. It is believed that his conclusions are in error.

1/ Let it be granted for the sake of discussion that his cumulative curve A has been obtained and that the histogram A has been constructed from this curve (the writer is inclined to think that the histogram data were obtained and the curve was constructed from them, but reference No. 1 was not available) and, furthermore, that graphically and theoretically the histogram "expresses" the curve, and vice versa.

Let it be granted also that curve B is identical with curve A, and that histogram B is so constructed that it fits curve B, i.e., that there are no inconsistencies in drawing.

Using the methods outlined by Wentworth (Bull. Geol. Soc. America, vol. 40), let us find the mean size of the particles of the sediment represented by histogram A. The mean size is found to be 0.566 mm. But if we make a like calculation for histogram B, the mean size turns out to be 0.519 mm.! Since the mean size of the particles of a sediment is a physical fact entirely independent of methods of calculation or of units employed, the only conclusion is that *histograms A and B, although fitted to identical curves, are the histograms of two different and distinct sediments.* Galliher's main contention thereby loses all cogency.

The error is shown in another way if we compute the standard deviation (S. D.) on the basis of the data given in the two histograms. The S. D. for the sediment of histogram A is 0.54, whereas that for B is 0.48. This result agrees with common sense. The S. D. is a measure of the scatter ("lack of sorting") about the mean, and visual inspection suggests that the scatter is greater in A than in B, as is found to be the case. The difference is not great, and is not perceptible in the cumulative curves as drawn.

Further generalization is possible. The slope of a cumulative curve (which is the total integral of the normal curve) is a function of the S. D. The S. D. of even the same sediment is changed by a change in the units of measurement. Hence, if one changes the units of measurement of the *same sediment* a new cumulative curve will result because of its dependence on the value of the S. D. Therefore the cumulative curve is just as "sensitive" to a change in units of measurement as is the histogram, and is, in that respect, no more nor no less useful than the latter.

A corollary of the foregoing is that to a given cumulative curve the *same sediment* can be fitted by *one histogram only.* One may think that so long as the total adds to 100% and the blocks "fit" the curve, the units of measurement can be changed at will. This is not so. Even though the mean be kept the same, any random change in the distribution of frequencies (percentages) will change the S. D., and thereby the slope of the curve that represents the data of the histogram. Galliher has not even kept the mean the same, and the fact that the histogram B of some unknown sediment fits the curve is of no moment.

2/ Galliher has missed the whole point of Wentworth's attempts to standardize the classification of sediments. The very point is that it *should not be* a "matter of personal opinion."

Workers in sediments recognized long ago Galliher's point that the shape of a histogram changes with change of units employed. Not only the histogram, but the cumulative curve changes. Therefore it is vital that the same units be employed in all measurements. The study of sediments by mechanical analysis is a purely empirical process. If any general laws are to result from its pursuit, it is essential that all conclusions and measurements be comparable,—that Wentworth's classification be rigidly followed unless a better is substituted.

3/ There is a deplorable tendency to put faith in the implied accuracy of the cumulative curve. The curves figured by Galliher are based (I take it) on four known points. The slope between any two of these points is based only on one's ability as a draftsman: the ability to draw a smooth curve through the four experimentally determined points. One cannot treat such a curve as one does a mathematical one, from which values of ordinate and abscissa can be read to the limit of accuracy desired. The histogram gives discrete values, with no implication as to the values that lie between; the cumulative curve based on just as few points simulates a far greater accuracy.

4/ It should further be mentioned that Goldman (Galliher's reference number 2, pp. 144-145) had arrived, in 1916, at Galliher's own final conclusion.

LINCOLN DRYDEN.

BRYN MAWR COLLEGE.

SCIENTIFIC INTELLIGENCE.

CHEMISTRY.

Laboratory Manual to accompany Principles of General Chemistry; by E. B. KELSEY and H. G. DIETRICH. Revised Edition. Pp. x, 206; 14 figs. New York, 1933. (The Macmillan Co., $1.50).—This is a very excellent Manual and one that well merits inspection and adoption in courses which assume a secondary school preparation in chemistry. The authors state that the use of Brinkley's "Principles of General Chemistry" is assumed, although the Manual can be readily adapted to other texts.

Section I, Inorganic Chemistry (133 pp.), omits the usual experiments dealing with hydrogen and oxygen but includes several quantitative experiments and some inorganic preparations. Section II, Elementary Qualitative Analysis (68 pp.), is designed for the elementary student. A wide variety of excellent experiments are given, more than are needed in a regular year's course, but this offers the instructor choice in the assignment of work. Alternate pages are blank in both sections. Blank data charts are provided for quantitative experiments. Numerous excellent and thought-provoking questions occur at the end of the various exercises.

It is well that the student is required throughout to balance oxidation-reduction equations electronically; also that, in exercises XXVI and XXVII, he is required to devise his own methods of separating mixtures of certain ions, after studying their individual properties. This method might well have been followed in the section on qualitative analysis.

The reviewer makes some suggestions in connection with the statements of the experiments. For example: in No. 2 (p. 41) he would have the voltage and amperage specified. Also on p. 83, he suggests the desirability of a blank test of the reagents for arsenic before the addition of the arsenic solution. PAUL H. FALL.

Ensykyopädie der technischen Chemie, 2d Edition; edited by DR. FRITZ ULLMAN. Vol. 10. Pp. 376; 305 figs. Berlin, 1932 (Urban and Schwarzenberg; 42.50 RM., 50 bound; Index 17 and 22 RM. Price of the entire work 522 RM., bound).—The present volume, with an index published separately, completes this Encyclopaedia which is undoubtedly the most extensive and best modern work in its field in any language. The applications of chemistry to technology of course, receive the most attention, but there is a wealth of data presented which makes it in many cases equally valuable as a chemical reference book in general. Comparison with the first edition shows, as might be expected, that much material is common to both, but new developments receive very full discussion. The article on hydrogen, particularly as regards its commercial production, in this final volume, is an illustration.

It is regrettable that the fall in the value of the dollar will make this monumental work more expensive for American readers.

H. W. FOOTE.

A Text Book of Chemistry; by H. A. Wootton and C. W. R. Hooker. Pp. vii, 488; 8 pls., 109 figs. Cambridge (University Press), New York, 1933 (The Macmillan Co., 1933, $1.75).—This text, which the English authors have written for beginning students, is a little difficult to place with respect to our American texts, particularly if one tries to decide whether it would be used—in this country—in a good secondary school, or in college. The book surveys the general field of chemistry very nicely, but it does not go so far into a number of topics as do many of our college texts. But it does give a most adequate foundation on which to build any further chemistry course which the student may desire to elect. Approximately one-third of the text is taken up by directions for laboratory work which the authors have kept separated from the rest of the material.

In the preface, the authors state that without a proper background of theory, it is difficult for the student to acquire and to classify facts; and that, since chemistry is a truly cultural subject, there is no necessity to present the facts in a dreary manner. We are glad to approve these ideas, and to emphasize that the development of the material along these lines is extremely well done. The discussion of a topic never seems hurried, and the authors' style is always good, and frequently delightful. In every case, the entire dependence of theory on experimental facts is carefully brought out, and then the usefulness of the theory, or its extension to explain other facts, is indicated.

Again comparing this text with the "average" American text, we find a few surprises. In the first place, the topic of ionization is not introduced until the study of non-metals is completed; second, we note that only about 30 pages in all are devoted to the chemistry of metals; and finally, we find no reference to atomic structure anywhere in the book. We do not feel that these differences constitute any particular drawback so far as the student is concerned. He will have gained a good footing in the fundamentals and can pursue these other topics at his pleasure. On the other hand, this difference in emphasis will make the text difficult to adapt to many of our school and college requirements.

The experimental work included in the second part of the text, is simple, but well chosen, and adequate to illustrate the descriptive sections.

E. B. KELSEY.

PHYSICS.

The Inventor and his World; by H. STAFFORD HATFIELD. Pp. v, 259; 3 figs. New York, 1933 (E. P. Dutton and Co., $2.40).—The subject of invention is one which appeals to a large group among the reading public. The marvels of our age are considered to be chiefly marvels of invention, and any treatment of the subject almost necessarily provides an account of the inventor as well as his work, thus adding a human interest which is often absent in the study of a scientific topic. In fact, the chief point of interest is most likely to be how the inventor was led to devise his inventions. The answer to this question, however, does not form the chief theme of the present book, although many instances are to be found along this line. Even though the author admits that invention is rarely considered in the choice of a profession and that as a class inventors are far from numerous, nevertheless much of the book might come under the head of advice to the would-be inventor. In spite of this practical vocational advice, the book should be interesting to the average reader. Not only is it written in interesting fashion, but it furnishes a clear picture of the inventor, his faults, his virtues, his tireless industry and unflagging enthusiasm in the face of disappointments and handicaps, and his occasional flashes of genius. It becomes apparent to us that the true inventor is preeminently an idealist rather than a practical man, contradictory as this may seem, and one who is closely akin to the artist. The latter part of the book is devoted to specific accounts of invention in the various fields of science, from mechanical to biological invention. Finally, the existing patent laws (chiefly in England) are examined and definite suggestions made for their improvement. An extensive bibliography is provided, classified by chapters in the text. A. T. W.

The Universe of Light; by SIR WILLIAM BRAGG. Pp. 279; 26 pls., 110 figs. New York, 1933 (The Macmillan Co., $3.50).—A distinguished scientist makes his return before the general reading public in the present volume. This return is very welcome, as his writing has both charm and clarity. The *Universe of Light* is stated to have had its origin in the Christmas lectures of the Royal Institution for juvenile audiences. In these lectures Sir William Bragg has continued a tradition that was started by Michael Faraday. In its present extended (and, of course, more advanced) book form the topic is a most happy one at the present time, for much of the fascinating material of modern physics has been directly or indirectly due to research in the subject of light. The aim of the book is to show the historical development of this subject leading up to the puzzling and sensational evidence concerning the nature of matter and of radiation. The sequence of topics chosen are: the nature of light; the eye and vision; color and its origin; the polarisation of light; light from the sky, sun and stars; X-rays; the wave and the corpuscle. The descriptions, the explanatory diagrams, and the explanations themselves are extremely well considered and should be clearly understood by the average reader. In addition, much that is of general interest is presented by way of illustration, such as optical illusions, curious manifestations of light in every-day life, and pictures of historic experiments, from old prints. The illustrations are truly remarkable. It is safe to say that seldom, if ever, has a collection of photographs been made of physical experiments so carefully designed and reproduced to show clearly the points intended and their outstanding details. A. T. W.

Smithsonian Physical Tables (Eighth revised edition): prepared by FREDERICK E. FOWLE, Smithsonian Astrophysical Laboratory. Pp. liv, 682; 870 tables. Washington, 1933. The Smithsonian Institution (Lord Baltimore Press).—This eighth revision of *The Smithsonian Physical Tables* brings up to date this handy book of tables, of which the seventh revision of 1919 had three subsequent editions. The aim of the editor has been not only the difficult task of incorporating very extensive new and revised material into the new volume, but also as far as possible to keep the volume within a convenient size. This purpose has been well fulfilled though it has necessitated references in many cases to more complete tables, such as the *International Critical Tables.* In addition to the expected additions in spectroscopy and in molecular and atomic physics, special reference may be made to the large extension of material under the subjects of astronomy, geophysics, aerodynamics and acoustics. A. T. W.

The New Background of Science; by SIR JAMES JEANS. Pp. viii, 301; 9 figs., 1 pl. New York, 1933 (The Macmillan Co., $2.50).—In this book the author, in the opinion of the reviewer, surpasses the high standards he has already set. In his delightful style he undertakes the exposition of modern physical concepts and their implications. The reader is not only told the results of modern fundamental research in physics and cosmogony, but is given more than a glimpse of the manner in which these results were obtained.

Starting with a critical and semi-historical discussion into man's approach to the external world, the methods of science are clearly portrayed, with examples from astronomy and relativity on the one hand, and atomic physics and quantum theory on the other. This chapter closes with an inquiry into what, after all, the scientist is seeking. The framework of the external world is then examined; this recalls to a certain extent the author's previous writings. In an interesting manner the growth of general mechanical laws is then briefly traced and their relation shown to the latest speculations concerning the universe. It is when the present conception of matter and radiation, "the texture of the external world," is explained that Jeans' power of exposition reaches its greatest heights. Here, with astonishing clarity, he describes the dual nature of both particle and photon, and with liberal use of analogy conducts the reader through the intricate maze of present-day atomic theory, even to the extent of expounding Heisenberg's matrix mechanics and the wave mechanics of de Broglie and Schrödinger. Brilliant as the exposition is, the non-mathematically minded reader will not follow this discussion in most of its details. An understanding of these details is not, however, necessary in order to follow the account of the principle of indeterminacy which is next discussed. The closing chapter is in philosophical vein and concerns the attempt to harmonize conception of events in the universe, as interpreted by science, with these events as ordinarily and obviously conceived in every-day life. The view-point is critical and quite impartial. The statements of leading thinkers are quoted and compared with a view toward finding what unanimity of opinion exists. Jeans draws no definite conclusion nor does he commit himself to a definite stand in this matter beyond the statement that "the law and order which we find in the universe are most easily described—and also, I think, most easily explained—in the language of idealism." A. T. W.

GEOLOGY AND MINERALOGY.

The Jurassic System in Great Britain; by W. J. ARKELL. Pp. xii, 681; 13 pls. and sketch maps; 97 figs. Oxford University Press ($7.75), 1933.—At the beginning of his preface, Doctor Arkell says, speaking of the English Jurassic: "We are wardens of a classic area, for our cliffs and quarries are the standards of comparison for the whole world . . . In our Jurassic rocks all the principles of stratigraphy are illustrated perhaps more clearly than in any other part of the geological record. Palaeontologically, too, the system contains an unequalled wealth of materials; and for the evolutionist, the ecologist and the palaeogeographer no more favourable field exists." This preëminence of the British in Jurassic studies has been true since the days of "Strata" Smith, more than a century ago.

It was the chief aim of the author to tell in a general way what is known of the Jurassic rocks of the British Isles, and not to furnish a handbook; the known detail is enormous, as is indicated by his bibliography of over 1200 titles, and threatens to hide the generalizations so much needed by stratigraphers outside of Britain. He began with the idea of synchronizing the Jurassic of his homeland with that of the Continent, but he found the difficulties so great that he settled down "to give descriptions and correlations of the Jurassic rocks of the British Isles, properly arranged as documents of history, and to draw as many historical conclusions from them as possible. The system of classification is therefore a secondary consideration, and all that is required of it is efficiency" (p. 1). How well Arkell has done his work is attested by F. L. Kitchin, paleontologist and stratigrapher of the British Geological Survey, who correctly says: "The merits of this remarkable book place it at once among the classics of stratigraphical literature."

The book-making is fine, as is to be expected of the Clarendon Press; the only criticism is that the thickness of the paper makes the book too bulky to be easily handled.

The volume is in four parts: I, Classification and Chronology (38 pages); II, Distribution and Tectonics (58); III, Stratigraphy (14 chapters covering 460 pages); IV, Palaeogeography (43). Two appendices deal with coral reefs, geosynclines, peneplains, and the stage names so far proposed, and are followed by a bibliography and index. Part I is a mine of information for stratigraphers, since it sets forth the history of how and by whom the principles of stratigraphy and correlation were brought to their present high stand; this history begins with William Smith and continues through the striking advances made by D'Orbigny, Quenstedt, Oppel, Buckman, and a host of other workers. Part II, dealing with the troughs of sedimentation and their tectonic history, presents an analysis of the Paleozoic platform on which the Jurassic system was laid down, and then a most interesting search through the subsequent diastrophism to find out the original lay of the Jurassic strata and the effect of the deformation on sedimentation. Important orogenic movements took place during Lower Liassic time, at the close of the Middle Inferior Oolite, and there were many additional local warpings throughout the period.

Part IV, on the paleogeography of the British Isles during Jurassic time, is not only good reading, but is replete with information, well seasoned with excellent judgment. To Arkell, paleogeography is the "most fascinating but at the same time the most dangerous" part of his studies; to do justice to that of the Jurassic period "would require a second volume." Nevertheless we are thankful for these 43 pages, which to the reviewer are the most valuable section of the book. The two greatest faunal controls in the paleogeography of the English Jurassic are the distribution of the corals and that of the ammonites. Corals are of shallow seas without strong currents, and with them go certain kinds of molluscs, whereas the ammonites lived in seas that were more open and better aërated. Where the deltaic or estuarine type of deposition prevailed, "neither corals nor ammonites existed; but in the districts where other types of deposit were being formed, either ammonites were autochthonous or corals, but never both" (p. 567). Of paleogeographic maps, Arkell presents but two, one of Lower Liassic and the other of Bathonian time. We wish there were many more. "Around the margins of the land," he says, "the seas transgressed and regressed with an unceasing ebb and flow, as in one age subsidence exceeded elevation and in another elevation overcame subsidence. On the whole, however, the upward tendency prevailed on the land and the downward in the troughs, until in the end the centres of the troughs had subsided between 3000 and 4000 feet, and they had become filled with the richly-fossiliferous and inexhaustibly interesting series of varied sediments which we call the Jurassic system" (p. 599). "The whole of North-West Europe is, and was in the Jurassic period, a large geanticline (Meso- and Palaeo-Europe) upon which continental (epeiric) seas occupied shallow troughs. To the south lay the deep geosyncline of Tethys, corresponding with what is now Neo-Europe—the Alps and the Mediterranean" (p. 58).

The third and main part of this valuable book has to do with the detailed areal stratigraphy of the deposits laid down by the seven oceanic spreadings into the troughs and the Tethyian geosyncline of the British Isles. Arkell begins the Jurassic with the Rhaetic and closes it with the Purbeck, which is the equivalent of the Tithonian of the continent, and which goes unbroken into the freshwater deposits of the Wealden of Early Cretaceous time. The Jurassic system has 69 recognized faunal zones, but the stratigraphic divisions are far more numerous.

Finally, the guide fossils are well illustrated on 13 plates. Of ammonites there are 66 species, of molluscs 17, and of ostracods 7. Truly, a classic treatment of a classic area! C. S.

Pliocene Floras of California; Pp. 112, 13 pls.; by ERLING DORF. Carnegie Institution of Washington. No. 412; Contributions to Paleontology, September, 1933.—The more detailed comparison of the Pliocene and modern Forest indicates that the climatic conditions during the local lower Pliocene were somewhat dryer and warmer than now, the effect being the apparent restriction of the Redwood Belt and some elimination of Tertiary types.—*Woods from the Ricardo Pliocene of Last Chance Gulch, California.* Pp. 113-134; 5 pls.; by IRMA E. WEBBER. A half dozen petrified dicot and pine woods with a cypress and a palm are approximated to their present day local equivalents. This is a clear, valid, and excellent study. G. R. W.

Fossil Floras of the Yellowstone National Park. Part I, *Coniferous Woods of Lamar River Flora*; by CHARLES B. READ. Pp. 19, 5 pls. As above, Publication No. 416.—This describes several new species of *Pinus*, a *Sequoia*, and a *Cupressinoxylon.* These are considered of either lower Oligocene or upper Eocene age.—II. *The Trout Creek Flora of Southeastern Oregon*; Pp. 68, pls. 3-16; by HARRY D. MACGINITIE.—This flora, of several dozen dicots and a few conifers, is held of Miocene age. It mainly consists in imprints from an interpolated series of diatomite strata, being preserved in much beauty of detail. Sedimentary conditions are noted, and climatic indices discussed.

Chamberlin and Salisbury's College Text-book of Geology, Second Edition. Part I. Revised by ROLLIN T. CHAMBERLIN and PAUL MACCLINTOCK. Pp. xi, 445; 19 pls., 376 figs. New York, 1933 (Henry Holt and Co., $3.00).—This new edition of a well-known book superficially resembles the preceding one, except that an apparent decrease in size has been attained by adoption of thinner paper. Influence of other college text-books which have been revised extensively, or of new ones which have appeared recently, is evident in some of the diagrams and text material that have been added. The first 289 pages are devoted to gradational process; the remaining pages treat diastrophism, vulcanism, and development of mountains.

Block diagrams are used extensively, but the majority fail to give that picture of distance and correlation of record with origin which should be their great advantage. Specifically, river-valley blocks such as figures 98 and 107 resemble a group of similar cross sections put together; they give a picture never seen in nature and convey an erroneous impression to the reader; simple cross sections or the drawings of Holmes might be substituted to advantage. In like manner inattention to detail gives the impression that the intake to an aquifer of an artesian system is at the crest of a hogback.

The main additions to the book deserve mention. Erosion in arid regions and origin of pediments receive well-balanced presentation. Effect of changes of level have fuller treatment and are amply illustrated by Johnson's diagrams of drainage developments in the Appalachians; but the reader is left in some doubt whether levels made at certain stages are pene*plains* or pene*planes*. Estimates of amount of emanations by specific volcanoes give a good picture of chemical activity about them, and the intermediate position of necks between lava and tuff above and complex intrusive forms below is explained commendably. The largest single addition is a chapter on development of mountains which follows closely the plan of a chapter on mountains in another text-book.

Inconsistencies appear elsewhere than in spelling. Treatment of the cause of diastrophism after description of results is an improvement that could have been made complete by discussing causes of earthquakes after description of effects rather than before. The broader results of diastrophism and vulcanism are illustrated by two-dimensional cross sections, as in previous editions, rather than by aerial photographs which are available in such number today. The halftone figures are reproduced well and, excepting those illustrating monadnocks and disintegration by weathering, are well chosen.

GEO. W. BAIN.

The Country around Torquay; by W. A. E. USSHER, second edition (revised) by W. LLOYD with Paleontology by C. P. CHATWIN and Igneous Petrography by W. G. SHANNON. Memoirs of the Geological Survey of England and Wales, Explanation of Sheet 350. Pp. xiii, 169; 7 pls. and 20 figs. London, 1933 (4/-, postage extra).—The area described in this report comprises some 100 square miles bordering the lower reaches of the River Dart in southeastern Devon. The first work on the area was embodied in a geologic map published in 1840. The map of which this memoir is an explanation (New Series, Sheet 350) was issued in 1898 and the first edition of the memoir appeared in 1903.

Additional field work has corroborated the interpretations of the earlier workers; so the present edition is merely supplementary to the earlier. In an introductory chapter the general areal, topographic, stratigraphic, and structural relations are outlined. Six chapters are devoted to descriptions of the sedimentary rocks, which are chiefly Devonian. The reviser is inclined to regard as Triassic the New Red rocks, which are represented on the map as Permian. Pleistocene and Recent deposits are discussed with special reference to Pleistocene changes of level and the bearing of cave deposits on the history of early man in the region. Permo-Carboniferous, Jurassic, Cretaceous, and Tertiary rocks are not found in the area. There is a general account of the rocks of each period, followed in each case by detailed descriptions of sections with illustrations and directions for reaching each section. This feature makes the memoir particularly suitable for use as a guidebook.

There has been added in this second edition systematic treatment of the paleontology of the Lower Devonian, the petrography of the igneous rocks, and the economic products of the area. Thus it constitutes a well rounded report on the country around Torquay and should be very useful not only to students of that area, but also to students who have a more general interest in the British Devonian. EARL INGERSON.

History of the Theory of Ore Deposits, with a chapter on the Rise of Petrology; by THOMAS CROOK. Pp. 161. London, 1933 (Thomas Murby & Co., 10/6 net). New York (D. Van Nostrand Co.).—This is an interesting account of the growth of ideas on the origin of the ore-forming solutions. Other aspects of the theory of ore deposits are not considered. The treatment is by brief expositions of the ideas of those considered to have been the leaders of thought. After a short account of the views of the ancients, the ideas of Agricola (1494-1555), who was the first to have modern concepts of minerals, rocks, and ore deposits, are set forth. The seventeenth century is represented by Descartes, Steno, and Woodward, and so on down to the twentieth century, which is represented by Van Hise, Kemp, Lindgren, Goodchild, Morrow Campbell, and Spurr. Somewhat greater historical continuity results than would be expected from this method of treating history by personalities. It is interesting to read that some of the ideas of Werner reappear in Elie de Beaumont's paper of 1847 "Note sur les emanations volcaniques et metallifères," perhaps "the most important and influential paper ever published on the theory of ore deposits."

The author freely expresses his judgment on many matters. We read that Hutton was an ore-magma extremist, that Sterry Hunt's views had much influence and were later those of S. F. Emmons and Van Hise, and that the theory of magmatic waters has been pushed to ridiculous extremes in the United States. On p. 128 the brilliant ideas of V. M. Goldschmidt are wholly misinterpreted.

The concluding chapter on the rise of petrology discusses the various attempts at classification of rocks during the first half of the nineteenth and ends with an account of that by Naumann in 1847. One of the leading ideas of this chapter, as well as of the rest of the book, is that petrologists have made an enormous mistake by excluding ore deposits from their classifications of rocks and have thus greatly hampered the growth of petrology. The author, however, appears to be unaware of the extraordinary growth of igneous, sedimentary, and metamorphic petrology since 1890, a growth so great that no one man can hope now to master the entire field.

This book shows clearly that a history of ideas is likely to be subjective. American geologists will certainly not agree with the author's account of the development of the subject on this side of the Atlantic, nor with all of his evaluations. It is a readable, stimulating, even at times provocative, book, but it cannot be regarded as the definitive history of the theory of ore deposits.

ADOLPH KNOPF.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Atitlan. An Archaeological Study of Ancient Remains on the Borders of Lake Atitlan, Guatemala; by SAMUEL KIRKLAND LOTHROP. Carnegie Institution of Washington, Publication, No. 444, 1933. Quarto, pp. v, 122; 74 text figs.—Lake Atitlan is in the highlands of southwestern Guatemala. This work deals with a reconnaissance of some thirty sites containing Mayan remains situated in the region of Lake Atitlan and with excavations in the ruins called Chukumuk and Chuitinamit. In addition the author has incorporated certain data obtained in 1928 on behalf of the Museum of the American Indian, New York.

The archaeological remains discussed are from the territories of the three most powerful tribes living there at the time of the Spanish Conquest: Quiché, Cakchikuel, and Zutugil. The author does not consider the present Indian population and their complex social and religious organization, but he does review in part both what the Indians wrote about themselves and what the Spaniards wrote about them during the sixteenth century. The most important literary records penned by the Indians are the *Popol Vuh* and the *Titulo*, both by the Quiché. A manuscript covering Cakchikuel history has been published under the title "Annals of the Cakchikuels" and "Memorial de Tecpan Atitlan."

Excavations at Chukumuk revealed an early, middle and late occupation. The pottery of the early period in part resembles ceramics from the valley of Mexico dating from Zacatenco II and subsequent "early" periods. The middle Chukumuk period is represented by many complete vessels and may be correlated with Holmul and Peten pottery. The last ceramic phase at Chukumuk continues the decorative techniques of the second period.

Chuitinamit, a rocky hill covered with ancient remains, stands at the eastern base of the Volcano San Pedro. Carved boulders abound at Chuitinamit. The most imposing rock carving represents a conventionalized jaguar with open jaws and protruding tongue. Artifacts of stone are comparatively rare. Chuitinamit was a royal residence which may account for the superior quality of the pottery found there.

The author is to be commended on the results obtained. The work is beautifully illustrated throughout and accompanied by ample references to the literature. GEORGE GRANT MAC CURDY.

The Book of Chilam Balam of Chumayel; by RALPH L. ROYS. Carnegie Institution of Washington, Publ. No. 438, 1933. Quarto, pp. viii, 229; 2 pls.; 48 text figs., and a map.—Written in the Mayan language, the Books of Chilam Balam reflect more closely the thought of these Indians than any other records that are available. They are the sacred books of the Maya of Yucatan, named after their last priest, *Chilam* (the word means mouth-piece of the gods). The title of the work might well read: The Book of the Prophet Balam. The translation of the Book of Chilam Balam of Chumayel depends primarily on the reading given to the badly punctuated and often misspelled Maya text.

Many of the towns of northern Yucatan possessed Books of Chilam Balam, to which was added the name of the town in question. The Book dealt with here was from the village of Chumayel in the district of Tekax. The Prophet Balam lived during the latter part of the fifteenth century and the first of the sixteenth. The Books of Chilam Balam were written in the Mayan language but in the European script which the early missionaries adopted to express such sounds as were not found in Spanish. Many portions of these books are simply transcriptions of the old hieroglyphic manuscripts. None of them that have come down to us were compiled earlier than the latter part of the seventeenth century.

The Chumayel was a small quarto volume which appears to have originally consisted of fifty-eight numbered leaves. Although it dates from 1782, the language suggests the seventeenth century much more than it does the eighteenth. It was compiled by Don Juan Josef Hoil of Chumayel. Dr. Berendt made a copy of it in 1868, and Teobert Maler made the first photographs of it in 1887. In 1910 it was loaned to Dr. George B. Gordon, Director of the University Museum, Philadelphia, who published a handsome facsimile reproduction (photographic) in 1913, and from this the present translation was made.

After being photographed by the University Museum, the original was returned to the then owner, Don Ricardo Figueroa, in whose house Dr. S. G. Morley saw it in 1913. After Figueroa's death the original was sent in 1915 to the Cespedes Library in Merida, but when Morley visited the library in 1918, it had disappeared and its whereabouts are still unknown. It is therefore nothing short of providential that we have the photographic copy by Maler, now in the Gates collection and the one by Gordon, which was published as Volume V of the University Museum's Anthropological Series. GEORGE GRANT MAC CURDY.

PUBLICATIONS RECENTLY RECEIVED.

High Gods in North America. Upton Lectures in Religion, Manchester College, Oxford, 1932; by W. Schmidt. New York, 1933 (Oxford University Press, $2.75).

Carnegie Institution of Washington. News Service Bulletin. Vol. III, No. 11. Energy Consumption in Physical and Mental Effort.

Rassenkunde und Rassengeschichte der Menschheit von Egon Freiherr von Eickstedt. Stuttgart, 1934 (Ferdinand Enke Verlag, RM. 72.50, bound RM. 76.50).

Elements of a National Mineral Policy, prepared by The Mineral Inquiry, C. K. Leith, Chairman. New York, 1933 (29 West 39th St.), $1.25.

The Determination of the Feldspars in Thin Section; by Karl Chudoba, translated by W. Q. Kennedy. London, 1933 (Thomas Murby & Co., paper 4/6, cloth 6/6).

British Economic Grasses; Burr and Turner. London, 1933 (Edward Arnold & Co., New York, Longmans, Green & Co., $3.75).

OBITUARY.

DR. HENRY STEPHENS WASHINGTON, well-known as a petrologist, and associated with the Geophysical Laboratory of the Carnegie Institution since 1912, died on January 7, when within a week of being sixty-seven. His extensive and highly valuable work on the composition of igneous rocks, the analyses of their constituent minerals, and the field study of volcanoes, gave him a prominent place among geologists. He thus won honors from many of the learned Societies of the world.

DR. ALLISON W. SLOCUM, professor of physics at the University of Vermont, died on December 10 at the age of sixty-seven.

DR. WILHELM W. O. MIELCK, director of the Biological Station at Heligoland, died on October 5 at the age of fifty-four.

MR. JAMES H. GIBBONEY, analyst of the Virginia Geological Survey, and chief chemist of the Norfolk and Western Ry., died on October 31 at the age of fifty-four.

DR. JAMES COSSAR EWART, professor of natural history at the University of Edinburgh for forty-five years, died on January 1 at the age of eighty-two.

BARON ALPHONSE BERGET, professor of oceanography and physics in Paris, died on December 29 at the age of seventy-three. He was the author of works on oceanography, geodesy, and navigation.

DR. GUSTAV EMBDEN, professor of chemical physiology at the University of Frankfort-on-Main, died on July 25, 1933, at the age of fifty-nine.

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MARCH 1934

PRELIMINARY NOTICE OF NEW MAN-LIKE APES FROM INDIA.

SCIENTIFIC RESULTS OF THE YALE NORTH INDIA EXPEDITION. REPORTS ON VERTEBRATE PALEONTOLOGY.

G. EDWARD LEWIS.

PALEONTOLOGIST, YALE NORTH INDIA EXPEDITION.

While it is generally agreed that the recent Hominidae and Simiidae admit of derivation from forms structurally close to the several species of the genus *Dryopithecus*, the author believes that two of the genera described herewith represent a much closer approximation to the Hominidae than other genera hitherto recorded. For his interest in the study of these anthropoids and assistance in matters incident to publication, thanks are due to Dr. R. S. Lull. The author is no less indebted to Dr. Malcolm R. Thorpe and to Dr. William K. Gregory for helpful advice and suggestions. The latter, who examined accurate casts and photographs of the Yale Siwalik anthropoids, is in general agreement with the conclusions reached, and points out two pertinent facts: (1) With our increasing knowledge of the higher fossil anthropoids, attendant upon new discoveries and more detailed research, there will doubtless come a synthesis of various species now regarded as distinct. (2) At the present time, however, perhaps the best plan is to differentiate between the diverse forms discovered to date when the evidence warrants such procedure.

In addition to future syntheses of genera and species, it is very probable that future discoveries and research will lead to a more detailed differentiation of genera and species now recognized. At present, the taxonomy of the fossil anthropoids is based almost entirely upon the dentition as a whole or in part, but are the distinctions between isolated teeth, between several adjacent cheek-teeth, or between the complete upper and lower dentition of such recent genera as *Gorilla* and *Pan* (or *Cercopithecus, Macacus,* and *Semnopithecus*) com-

AM. JOUR. SC.—FIFTH SERIES, VOL. XXVII, NO. 159, MARCH, 1934.

parable in magnitude to those drawn between the same teeth of the various genera of fossil Simiidae, or even to those drawn between the several species of *Dryopithecus*? This must be looked upon as a moot question. Moreover, sexual differences undoubtedly complicate the problem. Abel (1 - p. 33), for instance, distinguishes two divergent types of *Dryopithecus fontani*, and Pilgrim (20 - p. 14) expresses the opinion that two distinct species, or possibly two different genera are represented.

As indicated by the title, the present paper is a preliminary one. A more adequate memoir on the Yale North India Expedition primates will be submitted in the future. The material was all collected by the author in 1932.

SYSTEMATIC DESCRIPTION.

Order PRIMATES.
Suborder ANTHROPOIDEA.
Series CATARRHINI.
Family SIMIIDAE (HOMINIDAE?)
Genus RAMAPITHECUS[1], gen. nov.

Generic Characters.—Simiidae (Hominidae?) in which the dentition parallels the hominid type in its broader aspects. The dental arcade of the upper jaw is parabolic, rather than U-shaped as in recent Simiidae, and hence the palate broadens posteriorly. The cheek-teeth of opposite sides of the jaw are more widely separated posteriorly than anteriorly, rather than approximately equidistant from M^2 to P^3. The face is very slightly prognathous, as contrasted with recent Simiidae. There are no diastemata in the dental series. The canine is small, not an antero-posteriorly elongated trenchant tusk but a hominid type with a transverse dimension exceeding the antero-posterior dimension.

Genotype.—*Ramapithecus brevirostris*, sp. nov.

RAMAPITHECUS BREVIROSTRIS, gen. et sp. nov.

(Plate I, figs. 1a and 1b.)

Holotype.—The right maxilla and premaxilla with M^2, M^1, P^4, P^3, the alveolus of the canine, the root of I^2, and the alveolus of I^1 (Y.P.M. No. 13799).

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[1] After *Rāma* (prince of Ayodhyā, deified protagonist of the Sanskrit epic *Rāmāyana* of the poet Vālmīki) + πίθηκος (*ape*).

Locality.—¼ mile east of Chakrana, 4 miles east of Hari Talyangar village, in northwestern Bilaspur Kehloor State, Simla Hills; Yale North India Expedition paleontological locality number 39, *Survey of India Map* No. 53 A/NE, C-6.

Horizon.—Pliocene. Either latest *Middle Siwalik* or basal *Upper Siwalik.*

Description.

M^2.—The paracone is much more strongly developed than the metacone, which is stronger than the successively weaker protocone and hypocone. The paracone and metacone fall steeply away from their apices on the buccal side, while the protocone and hypocone fall away more gently on the lingual side. The inclination from the apices of the paracone and metacone toward the centrum is even less steep, while the minimum is displayed in that of the two inner cusps toward the centrum. Between the protocone and the paracone there is a strong ridge (crista transversa anterior), and another connects the protocone and the metacone (crista obliqua), the two forming a distinct trigon. A well developed ridge connects the paracone and the metacone, but midway between these two cusps the broadly rounded sulcus is divided by a crack-like deepening, which continues two-thirds of the way down the buccal surface of the crown. This exceedingly narrow and compressed infolding of the enamel surface has its origin between the protocone and the paracone, and extends to the center of the trigon, where it bends sharply outward. At this point, there is a feeble development of a branch extending a mere fraction of a millimeter toward the posterior ridge of the trigon, but the main branch continues on to the buccal face as above noted. The fovea anterior is bounded by the crista transversa anterior and a minor ridge which proceeds from the paracone to the median portion of the above-mentioned crista along the foremost edge of the occlusal surface. There are traces of two folds running from the protocone down to the central sulcus of the trigon; but if they were originally more strongly developed, this feature has been masked by subsequent wear. The metacone is unornamented, although the buccal face has faint traces of what might be the vestiges of shallow folds. Crossing the sulcus obliquus, which divides the hypocone from the trigon, is a very weak ridge showing considerable wear and connecting the hypocone with the metacone. A crack-like infolding occurs in the sulcus

obliquus, but it does not extend to the buccal, lingual, or posterior surfaces of the crown. The hypocone has no ornamentation, and is divided from the protocone by a very shallow and rounded groove. Facets of moderate wear are distinctly noticeable, especially on the anterior and posterior edges of the occlusal surface of the crown. There is no cingulum. The horizontal section of this molar presents a sub-trapezoidal outline, the maximum transverse diameter of the tooth being 11.8 mm. between the protocone and the paracone, as compared to a minimum of 10.8 mm. for the posterior moiety. This points to a posterior reduction in the cheek-teeth of the maxilla, and we should expect a small M^3.

M^1.—This tooth is similar to M^2, but differs from the latter in the following respects: in the order of decreasing prominence, the cusps are arranged with the well developed metacone first, followed by the paracone, protocone, and an extremely weak hypocone. Wear has exposed the dentine in small pits on the protocone and hypocone, and may account for the fact that the crests between the protocone and paracone, the fovea anterior, and the ridge anterior to this furrow are all much more reduced than in M^2, the last two features having almost disappeared. The crista obliqua is more prominent than in M^2. The crack-like infolding of the sulcus of the trigon dichotomizes near the center of the trigon, the two rami not exceeding 1 mm. in length. Similarly, the like feature of the sulcus obliquus, although nearly removed by wear, extends well up the metacone in two branches. Traces of these infoldings of the sulci are to be observed on the crista obliqua. The anterior portion of the buccal surface of the paracone has one small furrow which extends half way to the limit of the enamel from the occlusal edge of the buccal surface. There is no cingulum. Facets of wear are more conspicuous than in M^2, and the horizontal section is sub-rectangular.

P^4.—The paracone is more strongly developed than is the protocone. In the paracone, the buccal and central surfaces incline equally away from the cusp, while in the protocone the lingual surface is steeply inclined away from the cusp as contrasted with the more nearly horizontal central surface. This character has apparently been accentuated by wear. Two moderately strong ridges join the paracone and protocone. The anterior one proceeds from the summit of the paracone inward and forward, gradually curving thus until it reaches

a point half way to the base of the protocone, whence it proceeds directly to the summit of the latter; it constitutes the anterior margin of the crown. The posterior ridge is the counterpart of the anterior one, reversed. Separated from the foremost ridge by the fovea anterior is the strong crista transversa anterior, just posterior to which are three conspicuous transverse grooves in the primitive trigon, the two anterior ones being joined centrally by a sharply defined, longitudinal, crack-like infolding, which extended to the hindmost groove prior to wear. The transverse grooves are much more strongly developed on the paracone than on the protocone, where they are but two in number and of small magnitude. A broad, shallow, vertical groove is feebly developed on the antero-buccal surface of the paracone, while three even less-marked grooves of like nature occupy the occlusalmost portion of the same surface posteriorly.

P^3.—While not as hominid a bicuspid as P^4, P^3 is nevertheless a progressive type. While the protocone is well developed, it is subordinate to the paracone. The fovea anterior is more strongly developed than in P^4, as are the grooves on the central and buccal faces of the paracone. In spite of this comparative difference, those on the buccal face are not salient features.

C.—The alveolus of the canine indicates that this tooth was of small size, and differed radically from that of recent and fossil Simiidae previously described in that it displays a regular, ellipsoid outline, with its long axis normal to the curve of the maxilla, premaxilla, and superior dental arcade; in other Simiidae, this long axis has a tangent relationship to the features specified.

I^2.—The root is present in the alveolus, but the crown has been lost. A small incisor close to the hominid type is indicated.

I^1.—Most of the alveolus has been preserved, and indicates that the size of the two incisors was approximately equal. The roots indicate that the incisors more nearly approached the vertical than is the case in the Simiidae known hitherto; the attendant slight prognathism is hominid.

As in the Hominidae, there are no diastemata. The dental arch is very much compressed. The nearest approach to a diastema occurs between the alveoli of the canine and second incisor, which are separated by a scant 2 mm.—no more than in many human specimens, and insufficient to produce a diastema between the crowns. The palate is relatively high. The premolars are strikingly bicuspid types with a marked antero-posterior sulcus, and represent a stage considerably advanced beyond that of the maxilla referred by Pilgrim (21 - p. 16) to *Dryopithecus punjabicus.* The molars are also of a more human type.

Hopwood (13 - pp. 455-456) has pointed out the differences and similarities between the upper dentition of *Proconsul* and *Dryopithecus.* The African genus has little in common with *Ramapithecus,* although the former shows several points of approach to *D. rhenanus. Proconsul* has cheek teeth of relatively short antero-posterior diameter which in this respect parallel *Ramapithecus,* but the very strong cingula are reminiscent of *D. rhenanus,* which represents a decidedly primitive stage of superior molar development as compared to the other dryopithecoids.

D. germanicus is apparently close to *D. punjabicus,* but not to *Ramapithecus.* By far the nearest approach to *Ramapithecus* is the superior molar—which I believe to be correctly designated by the author as the second—assigned by Glaessner to *D. darwini* (7 - p. 19). From *Sivapithecus, Ramapithecus* is distinguished by the more crowded dentition, and by the more hominid and less ape-like canine and incisors.

The high breadth indices, low and rounded cusps, and simple structure of the molar crowns; the extremely bicuspid premolars, the man-like canine and incisors; and the divergent dental arcade and very slight prognathism are characteristic of *Ramapithecus.*

RAMAPITHECUS HARIENSIS,[2] sp. nov.

(Plate I, figs. 2a and 2b.)

Holotype.—A fragment of the right maxilla containing the first and second molars (Y.P.M. No. 13807).

Locality.—¼ mile east of Hari Talyangar village, in northwestern Bilaspur Kehloor State, Simla Hills; Yale North India Expedition paleontological locality number 35, Hari Talyangar cuesta scarp, *Survey of India Map No.* 53 A/NE, B-6.

Horizon.—Provisionally referred to the lower *Middle Siwalik—Nagri.*

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[2] After the name of the nearest village; Hari is one of the multitudinous names of the Hindu deity Vishnu.

Description.

Decay had affected both molars during life, and prior to fossilization they were shifted from their normal position with relation to each other.

M^2.—The low hypocone is the only unbroken cusp. The buccal portion of the paracone and metacone has been lost, and the anterior moiety of the crown has been deformed by a fracture passing through the fovea anterior. This fracture has been filled up with sediment and the anterior wall of the crown has been displaced approximately 1.5 mm. The lingual cusps have been worn down to low relief, but the buccal cusps are quite prominent. There is a vestigial internal cingulum.

M^1.—Noticeably smaller than M^2; a primitive feature. No description can be given of the protocone and hypocone, since decay has left only their peripheries intact. The paracone and metacone are quite prominent, and bear marked facets of wear whose position is transverse. Had the tooth not been diseased to such an extent, this striking feature would in all probability be lacking. M^2 was less decayed than M^1, and is more reminiscent of *Ramapithecus brevirostris*. There is no cingulum.

The anterior and posterior pressure facets indicate that adjacent cheek-teeth were in contact with each other only along a four millimeter portion of their peripheries. This is in pronounced contrast to *Ramapithecus brevirostris*, in which the teeth are compressed linearly as a corollary to the shortening of the dental series, with the result that adjacent cheek-teeth are in contact at pressure facets seven millimeters in length. The species under consideration also reflects its less crowded dentition in the more rounded contours of the crown as viewed from the occlusal aspect.

Ramapithecus hariensis is in every respect more primitive than the genotype. This is precisely what one should expect, since it comes from the same general locality, but from a horizon some 2000 feet below.

Genus SUGRIVAPITHECUS,[3] gen. nov.

Generic Characters.—Simiidae (Hominidae?) in which the mandible is characterized by its divergent rami, well developed chin, laterally compressed and elongate cheek-teeth, hominid

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[3] After *Sugrīva*, king of the monkeys in the *Rāmāyana*.

P_4, small canine and incisors, and the antero-posterior crowding of the dentition.

Genotype.—Sugrivapithecus salmontanus, sp. nov.

SUGRIVAPITHECUS SALMONTANUS, gen. et sp. nov.

(Plate II, figs. 1a, 1b, and 1c.)

Holotype.—The left ramus with the alveolus and roots of M_3; the perfect M_2, M_1, and P_4; the roots of P_3, C, and I_2; and the alveolus of I_1 (Y.P.M. No. 13811).

Locality.—3¼ miles WSW of Hasnot near Dhok Potha, Dhala Nala, District Jhelum, Tahsil Jhelum, in the Punjab; Yale North India Expedition paleontological locality number 94; *Survey of India Map No.* 43 H/5, A-3.

Horizon.—Lower *Middle Siwalik.*

Description.

M_3.—Precise determinations are obviously impossible. An examination of the alveolus and roots, with relation to the posterior surface of M_2, indicates a minimum length not less than that of the latter, and probably a little greater. The talonid was more reduced with respect to the trigonid than in the anterior molars, but the breadth index must have been approximately the same.

M_2.—The stage of wear is moderate, but sufficient to have obscured the lesser folds of the crown. In descending order of prominence come the metaconid, entoconid, hypoconid, protoconid, and hypoconulid. It should be pointed out that the protoconid has been subjected to a greater degree of wear than the other cusps. The principal sulci conform to those of the *Dryopithecus* pattern. The sulcus between the protoconid and the hypoconid terminates on the buccal surface at the extremely reduced vestigial exterior cingulum. From the sulcus between the metaconid and the entoconid a branch is given off near the centrum, and is carried forward on the postero-central surface of the metaconid. Here it gives rise to four shallow grooves directed lingually for a distance slightly less than that to the lingual surface. Upon this latter surface is a groove proceeding downward from a crenature on the margin of the occlusal surface of the metaconid, and corresponding to the anteriormost of the shallow grooves referred to above. The well developed fovea posterior receives two

shallow grooves arising on the hypoconulid, as well as two slightly deeper grooves which have their origin on the entoconid. In addition, two shallow grooves from the antero-central face of the entoconid, one from the postero-central face of the protoconid, and three from the antero-central face of the metaconid are directed to the sulcus nearest each respective face. The anteriormost grooves of the protoconid and metaconid as above enumerated constitute the remainder of the fovea anterior, which could not have been very deep since it has already begun to disappear with a very little wear. A faint groove extends a short distance downward from the summit of the hypoconulid on its buccal surface. The latter cusp is displaced laterally from the midline of the tooth to a small degree.

M_1.—Very similar to M_2, but even longer in proportion to its breadth. The stage of wear is more advanced than in M_2; consequently the occlusal surface shows less sculpture. The anterior cusps are considerably higher than the posterior cusps; in M_2 they were more nearly of the same height. The fovea posterior has been more obscured by wear than the fovea anterior.

P_4.—A highly molariform bicuspid close to the hominid type. The protoconid is slightly higher than the metaconid. The antero-posterior sulcus is very well developed, and it receives several shallow grooves from the central faces of the protoconid and metaconid. The fovea posterior is better developed than the fovea anterior. The tooth is in general more hominid than simiid, and is a remote departure from the primitive type of *Dryopithecus fontani*.

P_3.—Conclusions as to the nature of this tooth must be based on inferences drawn from the study of the root. As is to be expected, P_3 is more ape-like than P_4. However, that it is progressive is demonstrated by the fact that it has been progressively rotated counter-clockwise due to extreme compression of the dental series. Nowhere in the mandible are there any diastemata.

C.—The canine has been very much reduced, and is closely crowded between the adjacent teeth. It bears an internal cingulum. There was a postero-lingual lobe, and the tooth is set partially internal to P_3.

I_2.—The root establishes the fact that this incisor was very slightly procumbent, to a degree within the range of that shown by the Hominidae.

I_1.—The alveolus indicates a tooth similar to I_2.

Sugrivapithecus exhibits many progressive characters, if we consider those characters leading up to the Hominidae as progressive. The low breadth indices of all the cheek-teeth constitute an anomalous feature, since the other characters of the premolar-molar series are progressive. It is possible that this feature is correlated with the light, thin ramus. The incisors, canine, and premolars, both individually and with relation to the rest of the dentition, are certainly of an advanced type. The canine is set internally to the front premolar as in man, and the small incisors could not have projected forward beyond it. In general, the jaw is reminiscent of *Homo, Sivapithecus*, and *Dryopithecus cautleyi* in numerous features. Gregory (8 - p. 292) referred to the ape-like canine and front premolar as the most unhuman features of *Sivapithecus*, but in *Sugrivapithecus* these differences have been lessened. Strangely enough, Pilgrim's first restoration of *Sivapithecus* (21 - figs. 1, 2) is highly suggestive of the characters to be observed in *Sugrivapithecus*. As shown by *Sivapithecus himalayensis*, a much reduced genial fossa characterizes this genus (Pilgrim, 22 - p. 4). *Sugrivapithecus* illustrates a symphysial stage intermediate between that of *Sivapithecus* and *Dryopithecus fontani*, as regards the cross-section, while the symphysis was shorter than in either of these genera. The ramus is not as deep, and is far less massive, than is the case with *Sivapithecus* or *Dryopithecus*. As in *Ramapithecus*, there are few significant features in common with *Proconsul*. Future discoveries and research should throw more light on *Sugrivapithecus*. The author believes that the genus probably was derived from the main stem along with *Sivapithecus*, but very soon diverged and began to specialize along its own peculiar lines.

Genus DRYOPITHECUS Lartet.

DRYOPITHECUS SP.

(Plate I, figs. 3a, 3b, and 3c.)

A single left upper canine (Y.P.M. No. 13809) from 2.5 miles WSW of Chinji village, District Attock, Tahsil Talagang, in the Punjab; Yale North India Expedition paleontological locality number 22, Kundal Nala, Kotukka (Shinh Dhakki) Reserved Forest, *Survey of India Map No.* 43 D/6, A-1; age upper *Chinji* (late *Lower Siwalik*). This tooth agrees in all essential features with Indian Museum specimen

D. 192, as described and figured by Pilgrim (20 - pp. 47-48, pl. II, figs. 3, 3a, 3b, 3c), except that the Yale specimen is only approximately ¾ the size of the one in the Indian Museum. The latter, as first described by Pilgrim, was referred to *Sivapithecus indicus*, but subsequent finds and research led him to suggest (21 - pp. 6-7) that it probably should be referred to some species of *Dryopithecus* whose lower canines show similar characters, as in *D. cautleyi* and *D. pilgrimi*. The present author is in entire agreement with this later view of Dr. Pilgrim, and the smaller and more delicate Yale specimen accentuates the validity of his interpretation, while emphasizing the dissimilarity to *Sivapithecus*. In the canines as well as in the cheek-teeth, the Indian species referred to *Dryopithecus* seem to be well removed from the European *Dryopithecus*. As will be pointed out below, this canine came from the same quarry as the type of *Adaetontherium incognitum* (Y.P.M. No. 13808).

DRYOPITHECUS CAUTLEYI Brown, Gregory, and Hellman.

(Plate II, fig. 2.)

An isolated left M_1 (Y.P.M. No. 13813) from 1.5 miles WSW of Chinji village, District Attock, Tahsil Talagang, in the Punjab; Yale North India Expedition paleontological locality number 21, *Survey of India Map No.* 43 D/6, B-1; age uppermost *Chinji*. This specimen agrees in all respects with the type described as *Dryopithecus cautleyi* (3 - pp. 4-5). The more elaborate sculpture of the Yale specimen does not entitle it to specific distinction, since it is typical of all unerupted teeth of higher primates, and is soon lost with a very little wear. That this specimen does represent an unerupted tooth there can be no doubt. There is no trace of roots although the crown has obviously not been broken off. There is very little dentine under the enamel of the crown.

DRYOPITHECUS SIVALENSIS, sp. nov.

(Plate I, fig. 5.)

Holotype.—A fragmentary right mandibular ramus, with M_3, M_2, and the alveolus and a portion of the root of M_1 (Y.P.M. No. 13806).

Locality.—¼ mile east of Hari Talyangar village, in northwestern Bilaspur Kehloor State, Simla Hills; Yale North

India Expedition paleontological locality number 35, Hari Talyangar cuesta scarp, *Survey of India Map No.* 53 A/NE, B-6.

Horizon.—Provisionally referred to the *Nagri*—Lower *Middle Siwalik.*

Description.

M_3.—The metaconid is the dominant cusp, the protoconid is slightly developed, and the remaining cusps have been greatly reduced by wear. While the fovea anterior has been preserved, there remains but a trace of the fovea posterior. The principal sulci are indicated by crack-like infoldings which are much obscured by wear and weathering, with the exception of that between the metaconid and the entoconid, a portion of which presents the appearance of a small pit. There is no trace of a cingulum. The crown narrows posteriorly, the hypoconulid being central in position and unusually large, forming a third lobe.

M_2.—The metaconid is markedly dominant, while the remaining cusps are of low relief and of approximately the same level due to wear. The remnants of the principal sulci and of the foveae anterior and posterior are preserved, but slightly more wear would have obliterated them. The hypoconid is central in position. There is no trace of a cingulum.

Although the ramus is not very deep, it is exceedingly broad and massive in proportion to the size of the molars, which are quite small as compared to those of most species of *Dryopithecus.* The association of the two molars offers something of a paradox. M_2 is very similar to that of *D. cautleyi* (3 - pp. 4-5, fig. 4) but M_3 is closer to *Neopithecus brancoi* than to any known species of *Dryopithecus.* This association bears out the views of Gregory (8 - p. 311) and Schlosser (23 - p. 267) regarding the origin and affinities of *Neopithecus.* The low relief, the exceptionally low breadth index, the characteristic hypoconulid, and the trilobate character all point to the close parallelism or relationship of *Neopithecus* and *D. sivalensis.* The author feels, however, that the generic affinity lies with *Dryopithecus* rather than with *Neopithecus.* The anomalous association of these two widely differing types of lower molars is accentuated by the fact that the breadth index of M_2 is greater than that of any other species of *Dryopithecus.* Although found at the same locality as several other primates, none of the different jaws or teeth could have been associated.

Genus BRAMAPITHECUS,[4] gen. nov.

Generic Characters.—Simiidae in which there has been an extreme reduction in the length of the lower molars as related to the width. Characterized by the fact that the molars of the mandible have been very much compressed antero-posteriorly, have rather high crowns, and a peculiar relief made up of the usual furrows complicated by numerous coarse grooves.

Genotype.—*Bramapithecus thorpei,*[5] sp. nov.

BRAMAPITHECUS THORPEI, gen. et sp. nov.

(Plate I, fig. 4.)

Holotype.—The left ramus bearing M_3, M_2, the alveolus and roots of M_1, and a portion of the alveolus and root of P_4 (Y.P.M. No. 13814).

Locality.—1.5 miles SE of Hasnot, 3 furlongs NW of Gulial, on the Andar Kas; District Jhelum, Tahsil Jhelum, in the Punjab; Yale North India Expedition paleontological locality number 81, *Survey of India Map No.* 43 H/5, B-3.

Horizon.—Upper *Chinji, Lower Siwalik.*

Description.

M_3.—The buccal cusps show a greater degree of wear than do the lingual cusps. The metaconid is extremely prominent, the entoconid somewhat less so, the hypoconid and hypoconulid are still lower, while the protoconid has been worn down most of all, the dentine being exposed in a small pit. The fovea posterior is well developed, but there remains only a trace of the fovea anterior. In addition to the principal folds of the *Dryopithecus* pattern, there are three marked, coarse grooves on the metaconid, radiating outward from the centrum. The hindmost bifurcates, its anterior branch dichotomizing in turn, the posterior ramus of this latter fork continuing over to the lingual surface and marking a crenation of the occlusal-lingual margin of the metaconid. The central groove also extends to the margin, over which it passes in a crenation to the lingual surface. The vestiges of an external cingulum are to be observed on the adjacent buccal surfaces of the protoconid and hypoconid, the former bearing the greater portion of it. The sulcus separating the cingulum from the adjacent cusps is continuous with that dividing the protoconid and hypoconid. The hypoconulid is much reduced, but stands out sharply from the hypoconid, from which it is separated by a sharp crenation. The hypoconulid occupies a lateral position. The "sixth cusp" is present and occupies a median position. This is a primitive feature. There is another small subordinate cusp between the sixth cusp and the entoconid, from which it is set off by a crenation.

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[4] After Brahmā, the creator and supreme soul of the universe, and first of the Hindu trinity.

[5] Dedicated to Doctor Malcolm Rutherford Thorpe as a token of appreciation and esteem.

M_2.—Much more worn than M_3. The metaconid is very prominent, while the other cusps have been worn to low relief. The dentine is exposed in small pits on the buccal cusps. Due to their original depth, the principal sulci are preserved. The subordinate grooves have been very nearly obliterated by wear, but their vestiges indicate a condition similar to that obtaining in M_3. The external cingulum was weaker than in M_3. The fovea anterior has been obliterated by wear, but there is a trace of the fovea posterior.

M_1.—The crown had been broken away and lost prior to collection, but the roots indicate that the size and proportions approached those of M_2. The position of the posterior root and the deep anterior pressure facet on M_2 indicate that these two adjacent teeth were crowded closely together.

P_4.—The root was less than 0.5 mm. from the root of M_1, so we have further evidence of crowding.

Bramapithecus exhibits several primitive features. On the other hand, the sculpture of the crowns is highly suggestive of many human molars. The deep folds, persistent in spite of severe wear, are notable features. The author is not prepared to embark on an extended study of the relationships of *Bramapithecus* at this time, but believes that the genus has affinities with *Dryopithecus*, and was probably derived from a common stock. It may very well lie near to the stem which led to the Hominidae proper.

INCERTAE SEDIS (anthropoid primate?)

ADAETONTHERIUM[6] INCOGNITUM, gen. et sp. nov.

(Plate II, fig. 3.)

Holotype.—The crown of a single tooth (Y.P.M. No. 13808).

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[6] ἀδάητον (strange) + θηρίον (animal).

Locality.—2.5 miles WSW of Chinji village, District Attock, Tahsil Talagang, in the Punjab; Yale North India Expedition paleontological locality number 22; Kundal Nala, Kotukka (Shinh Dhakki) Reserved Forest, *Survey of India Map No.* 43 D/6, A-1.

Horizon.—Upper *Chinji*, late *Lower Siwalik.*

Description.

As intimated previously, this specimen was found in the same quarry with the canine referred to ***Dryopithecus*** sp. The latter had weathered out of the matrix and was found at a distance of three meters from ***Adaetontherium incognitum***, which was imbedded ***in situ.*** The author is not inclined to believe that the two represent the same individual, although it is not impossible that this is the case. There is no certainty that this tooth belongs to any species of primate. Its characters appear to be more like those of the primates than those of any other order. The maximum horizontal dimension is 9.1 mm. and the minimum is 8.2 mm. The maximum height of the crown is 5.5 mm. The crown is characterized by a high relief and complex system of folds. There are two dominant cusps, alternating with two subordinate cusps, and separated by three major folds. Each of these folds is quite deep, and has numerous branches. These three major sulci arise from a common point in the center of the crown, and are deeply infolded, forming crack-like fissures. Similarities suggestive of unerupted milk-molars of recent Simiidae dissected by the author induce him to believe that ***Adaetontherium incognitum*** may represent the superior milk-molar of some Siwalik anthropoid. Dr. W. K. Gregory suggests that it may be an unerupted, aberrant, superior third molar of an anthropoid. A truly definitive judgment must await more extensive finds. At such a time, synthesis may be possible.

TABLE OF MEASUREMENTS AND INDICES OF HIGHER ANTHROPOIDS

The Yale specimens have been measured according to the method employed by Gregory and Hellman (10 - pp. 31, 55). Measurements are in millimeters.

Lower Dentition		*Sugrivapithecus salmontanus* (Y.P.M. No. 13811)	*Bramapithecus thorpei* (Y.P.M. No. 13814)	*Dryopithecus sivalensis* (Y.P.M. No. 13806)	*Dryopithecus cautleyi* (Y.P.M. No. 13813)	*Dryopithecus cautleyi* (After B., G., and H.)	*Dryopithecus frickae* (After B., G., and H.)	*Dryopithecus punjabicus* (After Pilgrim)
M_3	antero-posterior		11.1	11.0		13.7	14.0	12.5
	transverse		10.8	8.6		12.3	12.7	10.4
	breadth index		97	78		90	91	83
M_2	antero-posterior	12.6	10.0	10.5		12.6	13.5	11.6
	transverse	10.4	10.6	10.0		11.3	12.4	9.9
	breadth index	83	106	95		90	92	85
M_1	antero-posterior	11.0			10.8	10.6	11.5	
	transverse	9.0			9.8	9.5	11.0	
	breadth index	82			91	90	95	
P_4	antero-posterior	7.2				9.0	8.2	
	transverse	8.4				9.2	10.2	
	breadth index	117				118	113	

Lower Dentition		*Dryopithecus chinjiensis* (After Pilgrim)	*Dryopithecus giganteus* (After Pilgrim)	*Dryopithecus pilgrimi* (After B., G., and H.)	*Dryopithecus fontani* (St. Gaudens, after Pilgrim)	*Dryopithecus fontani* (Lerida, after Pilgrim)	*Dryopithecus darwini* (After Pilgrim)	*Dryopithecus rhenanus* (After Pilgrim)
M_3	antero-posterior	14.7	19.1		12.5	11.5	13.5	13.0
	transverse	12.7	15.3		10.5	9.5	11.8	10.5
	breadth index	86	80		84	83	87	81
M_2	antero-posterior				12.0	11.0		10.6
	transverse				10.5	9.5		9.2
	breadth index				87	86		87
M_1	antero-posterior				10.0	10.0		9.5
	transverse				10.5	9.0		8.8
	breadth index				105	90		93
P_4	antero-posterior			7.8	9.0			
	transverse			8.7	8.0			
	breadth index			111	89			

Lower Dentition		*Dryopithecus rhenanus* (After Pilgrim)	*Neopithecus brancoi* (After Pilgrim)	*Palaeopithecus sylvaticus* (After Pilgrim)	*Sivapithecus indicus* (After Pilgrim)	*Sivapithecus middlemissi* (After Pilgrim)	*Sivapithecus himalayensis* (After Pilgrim)	*Proconsul africanus* (After Hopwood)
M_3	antero-posterior	11.8	10.3	12.7	14.3	14.4		11.6
	transverse	9.8	7.8	11.6	13.4	13.2		8.9
	breadth index	83	76	91	94	92		77
M_2	antero-posterior	10.0		12.0	13.0	12.9	15.1	11.0
	transverse	8.4		11.2	12.3	12.3	13.7	10.8
	breadth index	84		93	95	95	91	91
M_1	antero-posterior	11.2		10.1	11.5		11.8	9.5
	transverse	9.5			10.6		10.9	9.4
	breadth index	85			92		92	99
P_4	antero-posterior			7.5	8.5		8.5	7.4
	transverse			10.0	9.9		11.2	8.9
	breadth index			75	116		76	120

TABLE OF MEASUREMENTS AND INDICES OF HIGHER ANTHROPOIDS.—*Cont.*

Upper Dentition		*Ramapithecus brevirostris* (Y.P.M. No. 13799)	*Ramapithecus hariensis* (Y.P.M. No. 13807)	*Dryopithecus sp.* (Y.P.M. No. 13809)	*Dryopithecus punjabicus* (After Pilgrim)	*Dryopithecus rhenanus* (After Pilgrim)	*Dryopithecus darwini* (After Glaessner)	*Dryopithecus germanicus* (From a figure)	*Sivapithecus indicus* (*Dryopithecus sp.* C) (After Pilgrim)	*Sivapithecus orientalis* (After Pilgrim)	*Palaeopithecus sivalensis* (After Pilgrim)	*Proconsul africanus* (After Hopwood)
M^2	antero-posterior	9.9	11.2		10.6	10.4	12.0	10.8	12.5	12.8	11.3	9.2
	transverse	11.9	12.7		11.4	11.0	13.6	11.3	14.0	14.2	12.9	11.3
	breadth index	120	114		107	106	113	105	112	111	114	123
M^1	antero-posterior	9.2	9.8		10.4	9.6			10.5	11.0	10.8	7.9
	transverse	10.9	11.3		11.3	10.0			13.5	12.0	12.0	9.6
	breadth index	119	115		109	104			128	109	111	122
P^4	antero-posterior	6.7			6.6					7.3	6.8	5.8
	transverse	10.0			9.7					12.0	11.4	8.9
	breadth index	149			147					164	168	152
P^3	antero-posterior	6.9			7.0					7.7	6.8	7.3
	transverse	10.3			9.5						11.4	9.4
	breadth index	148			136						168	129
C	antero-posterior			11.3					16.2	14.7	12.7	11.3
	transverse			8.2					10.6	12.3	11.9	9.1
	breadth index			73					66	84	94	81

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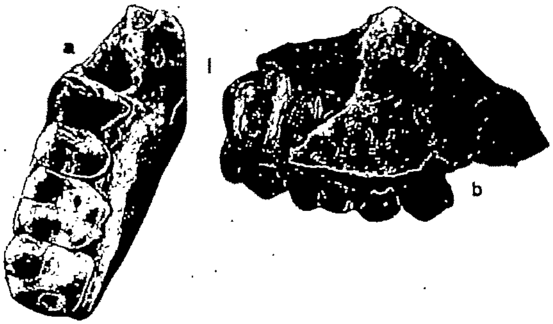

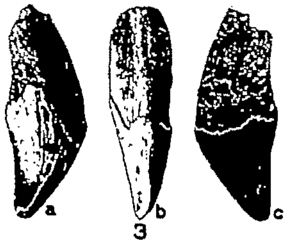

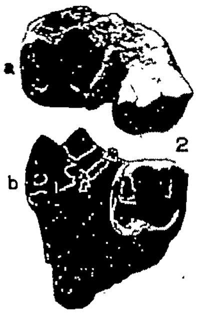

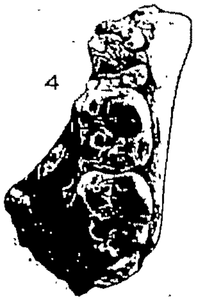

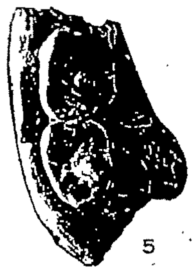

PLATE I

(All figures natural size.)

1. *Ramapithecus brevirostris*, gen. et sp. nov. Holotype Y.P.M. No. 13799.
   a) Occlusal aspect of right maxilla and premaxilla.
   b) Buccal aspect of right maxilla and premaxilla.
2. *Ramapithecus hariensis*, sp. nov. Holotype Y.P.M. No. 13807.
   a) Occlusal aspect of right M^2.
   b) Occlusal aspect of right M^1.
3. *Dryopithecus* sp. Y.P.M. No. 13809.
   a) Lingual aspect.
   b) Anterior aspect.
   c) Buccal aspect.
4. *Bramapithecus thorpei*, gen. et sp. nov. Holotype Y.P.M. No. 13814.
   Occlusal aspect of left mandibular ramus.
5. *Dryopithecus sivalensis*, sp. nov. Holotype Y.P.M. No. 13806.
   Occlusal aspect of right mandibular ramus.

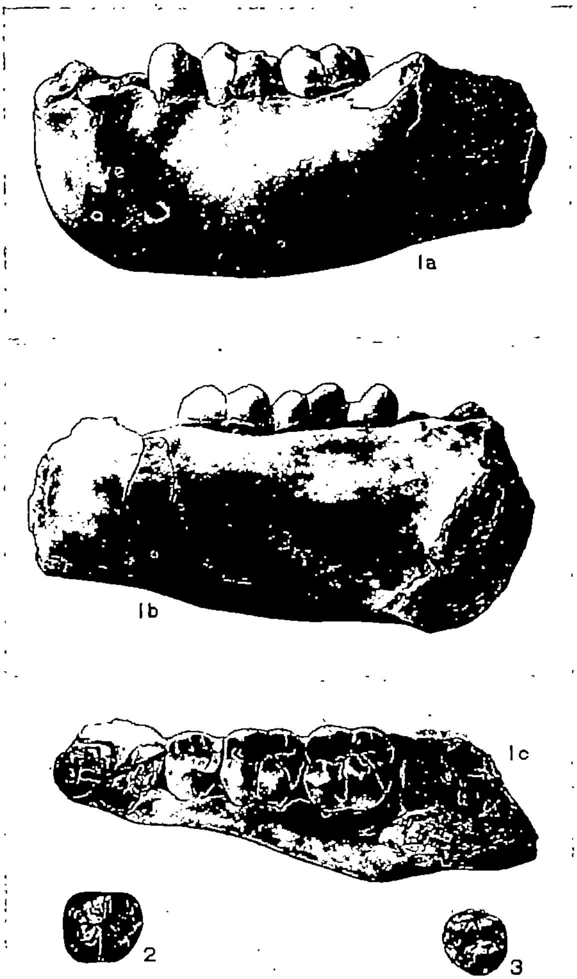

PLATE II

(All figures natural size.)

1. *Sugrivapithecus salmontanus*, gen. et sp. nov. Holotype Y.P.M. No. 13811.
   a) Buccal aspect of left mandibular ramus.
   b) Lingual aspect of left mandibular ramus.
   c) Occlusal aspect of left mandibular ramus.
2. *Dryopithecus cautleyi*. Y.P.M. No. 13813. Occlusal aspect of left M_1.
3. *Adaetontherium incognitum*, gen. et sp. nov. Holotype Y.P.M. No. 13808. Occlusal aspect.

THE JURASSIC AGE OF THE LAST GRANITOID INTRUSIVES IN THE KLAMATH MOUNTAINS AND SIERRA NEVADA, CALIFORNIA.

NORMAN E. A. HINDS.

INTRODUCTION.

In the Klamath Mountains of northern California and southern Oregon are many plutonic and hypabyssal igneous bodies intruded into the crust during the mid-Mesozoic Nevadan orogeny[1] which was responsible for the deformation of a vast area of western North America, extending, as many geologists believe, from Mexico and Lower California northward to Alaska and in the United States from eastern Utah to the Pacific Coast. The time of this deformation and associated magmatic intrusion has long been debated, and geologists have variously assigned it to the Upper Jurassic and the Lower Cretaceous. Among later writers on California geology who have discussed the problem, J. P. Smith,[2] Blackwelder,[3] Knopf,[4] Schuchert,[5] and Crickmay,[6] have given the date as Upper Jurassic. In the describing the geology of the Mother Lode system of the Sierra Nevada, Knopf writes,

> "The folding to which the Mariposa rocks were subjected and the intrusion of great volumes of granite into them . . . . probably took place in late Jurassic time for the revolution was of pre-Knoxville age, and the basal portion of the Knoxville is regarded by some geologists as of late Jurassic age. The Mariposa is considered to be late though not latest Jurassic and the break between the Mariposa and Knoxville does not coincide with the dividing line between the Jurassic and Cretaceous."

Schuchert states that

> "Although the intrusions may have been started in middle Jurassic time, the main injections took place at the close of the

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[1] For the mid-Mesozoic deformation of the western part of the Cordilleran syncline I have recently proposed the term Nevadan, Univ. of Calif. Publ., Dept., Geol. Sci., vol. 20, p. 378, 1932, as a modification of Nevadian applied by Blackwelder in 1914.

[2] Smith, J. P., The Geologic Formations of California, Calif. State Min. Bur., Bull. 72, pp. 32-33, 1916.

[3] Blackwelder, E., A Summary of the Orgenic Epochs in the Geologic History of North America, Jour. Geol., vol. 22, pp. 644-645, 1914.

[4] Knopf, A., The Mother Lode System of California, U. S. Geol. Survey, Prof. Paper 117, p. 14, 1929.

[5] Schuchert, C., Outlines of Historical Geology, New York, 1931, p. 204.

[6] Crickmay, C. H., Jurassic History of North America, Proc. Amer. Philos. Soc., Vol. 70, p. 88 ff., 1931.

period, extending into Lower Cretaceous time, and less significant upwellings went on even to the close of the Mesozoic era."

Crickmay believes in widespread deformation with possible intrusions of granitic magma in the early Upper Jurassic (between the Callovian and Argovian stages) followed by a second disturbance also accompanied by batholithic intrusion in the late Upper Jurassic (post-Portlandian), but in the Sierra Nevada and in the Klamath Mountains there is no evidence of a two-fold orogeny.

Lindgren,[7] Knopf in an earlier paper,[8] Lawson,[9] and Matthes[10] hold that the folding and intrusion of granitoid magma in the Sierran region occurred in early Cretaceous. Both Knopf and Matthes admit the possibility of a late Jurassic date since no definite stratigraphic evidence exists in the regions which they describe; on the maps published with their reports the batholithic rocks are listed as early Cretaceous. According to Lindgren,

> "The major features of the beginning of Cretaceous history in the Sierra consisted in the plication and welding of the Mariposa formation . . . . and finally the intrusion in the foundations of the range of enormous batholiths of dioritic and granitic magma."

Lawson writes of

> "The great revolution which raged throughout the western margin of the continent at the end of the Jurassic. . . . . Subsequent to the folding of the region there reached the deformed and dynamically metamorphosed rocks from below great invasions of granite magma."

The granite Lawson considers to be "post-Jurassic." The seal of approval of the United States Geological Survey is set on the Cretaceous age by Miss Wilmarth[11] who classes all of the Sierran granitoid bodies as "probably Cretaceous."

[7] Lindgren, W., The Tertiary Gravels of the Sierra Nevada of California, U. S. Geol. Surv., Prof. Paper 73, p. 44, 1911.

[8] Knopf, A., A Geological Reconnaissance in the Inyo Range and the Eastern Slope of the Sierra Nevada, California, U. S. Geol. Surv., Prof. Paper, 110, 1915.

[9] Lawson, A. C., The Cordilleran Shield, Proc. Third Pan-Pacific Sci. Cong., Tokyo, p. 375, 1926.

[10] Matthes, F. E., Geologic History of the Yosemite Valley, U. S. Geol. Surv., Prof. Paper 160, 1930.

[11] Wilmarth, M. Grace, Names and Definitions of the Geologic Units of California, U. S. Geol. Surv., Bull. 826, 1931.

Matthes,[12] in a recent publication notes that

> "At least two mountain systems have in turn occupied the place on which the present Sierra fault block now stands; the first was probably developed toward the end of Carboniferous time while the second was formed either at the end of the Jurassic period or at the beginning of the Cretaceous, and it was under and into the folds of this system that the magma of the compound batholith were poured."

Ernst Cloos[13] and Knopf[14] subscribe to this opinion.

Diller[15] and Ferguson,[16] discussing the geology of the Klamath Mountains, consider that the deformation and batholithic intrusion occurred either in the late Jurassic or early Cretaceous while Graton[17] believes that these events marked the close of Jurassic history in this region. J. P. Smith[18] states that

> "In the Klamath Mountains of Siskiyou, Shasta, and Del Norte counties, there are numerous batholiths of granite rocks, very like those of the Sierra Nevada, and supposed to belong to the same period. But since no fossiliferous sediments of later age than Upper Carboniferous are invaded by those rocks, no definite age can be assigned to them. And since the batholiths are isolated, we do not know that they belong to one great intrusive mass."

SOUTHERN KLAMATH MOUNTAINS.

In the southern Klamath Mountains, which suffered intense folding during the Nevadan deformation, much evidence has been secured which permits a more accurate dating of that event. In this region, the youngest formation involved in the folding is the Potem (Plate I, Jp), a thick series of marine sediments and volcanics originally classed as Liassic by Diller[19] on the basis of paleontologic studies made by Hyatt.

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[12] Matthes, F. E., Geography and Geology of the Sierra Nevada, XVI International Geol. Cong., Guidebook 16-Excursion C-1, pp. 33-34, 1933.

[13] Cloos, E., Structure of the Sierra Nevada Batholith, XVI International Geol. Cong., Guidebook 16-Excursion C-1, p. 40, 1933.

[14] Knopf, A., The Mother Lode System, XVI International Geol. Cong., Guidebook 16-Excursion C-1, p. 46, 1933.

[15] Diller, J. S., The Redding Folio, U. S. Geol. Surv., No. 138, p. 8, 1906.

[16] Ferguson, H. S., Gold Lodes of the Weaverville Quadrangle, U. S. Geol. Surv., Bull. **540**, p. 27, 1914.

[17] Graton, L. C., The Occurrence of Copper in Shasta County, California, U. S. Geol. Surv., Bull. **340**, p. 85, 1914.

[18] Smith, J. P., The Geologic Formations of California, Calif. State Min. Bur. Bull. 72, p. 40, 1916.

[19] Diller, J. S., op. cit., p. 1.

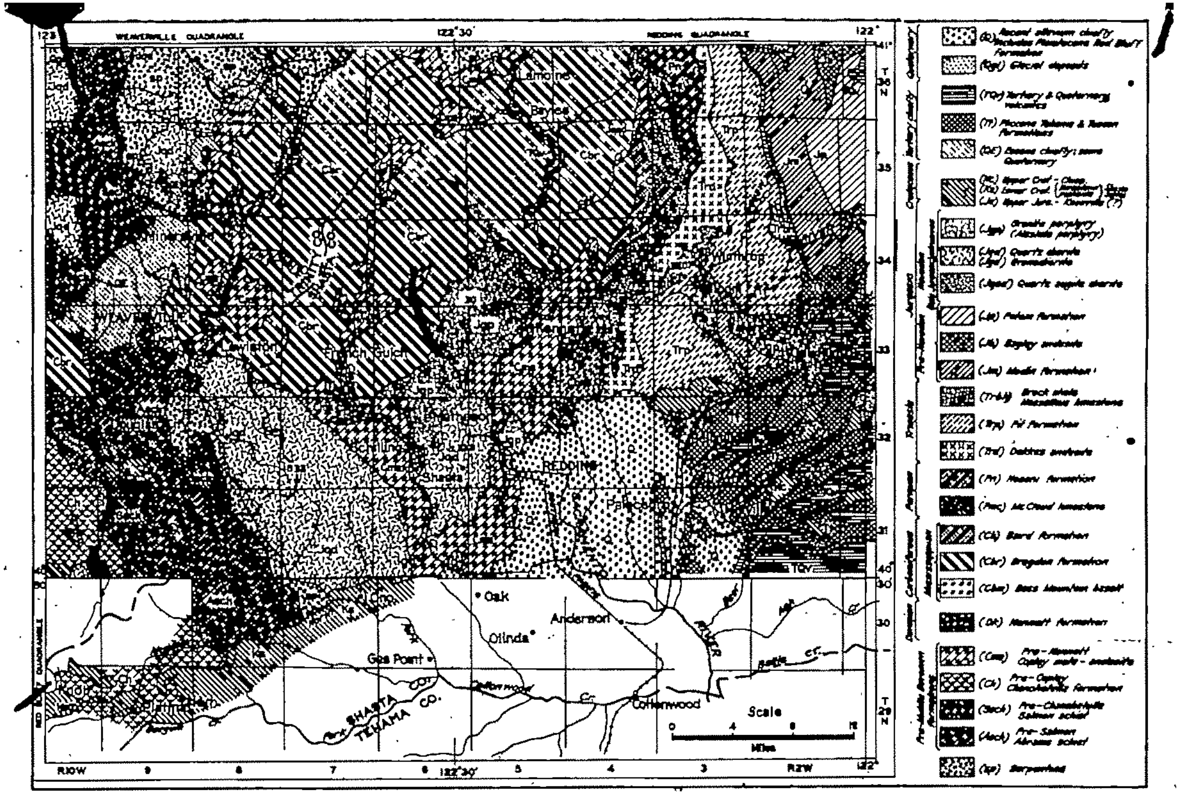

Plate I. Geologic map of the Redding and Weaverville quadrangles and the northwestern part of the Red Bluff quadrangle, northern California.

Redding quadrangle by J. S. Diller (1906), revised in part by N. E. A. Hinds and R. Dana Russell; Weaverville quadrangle by N. E. A. Hinds (1925-1930); northwestern part of Red Bluff quadrangle by N. E. A. Hinds and R. Dana Russell (1929).

Crickmay[20] has recently assigned the Potem to the Ludwigian stage of the Middle Jurassic. Later Jurassic beds may lie under the lava cap of the Cascade province which joins the Klamath Mountains on the east and which overlaps the Middle Jurassic and earlier formations. The great thickness of late Jurassic strata at the north end of the Sierra Nevada 50 miles to the south and the close relation of the Sierra Nevadan and Klamath provinces prior to the Nevadan deformation strongly suggest this. Below the Potem is a wide sequence of formations belonging to the Middle and Lower Jurassic, the Triassic, Permian, Lower Carboniferous, and Devonian; below the Devonian are at least four thick formations of unknown age. These have been described chiefly by Hershey, Diller, J. P. Smith, Ferguson, and Hinds.

The principal igneous bodies intruded into the crust in the southern Klamath region during the Nevadan orogeny are stocks, bosses and a small batholith of quartz augite diorite, a huge plutonic dike of quartz augite diorite, and two chonoliths of sodic granite porphyry. Many plutonic and hypabyssal dikes, sills and small, irregularly shaped bodies are also present. Some of these can be traced as offshoots of the larger masses; others are isolated but evidently are of the same age. Field relations show that all of these bodies, large and small, were not intruded at the same time but that they were intruded in successive stages during a single magmatic epoch. Northward in this province are other stocks, bosses, and small batholiths of quartz diorite and granodiorite very probably belonging to the Nevadan group. Older intrusives of Mesozoic and Paleozoic age, chiefly diorites and gabbros, are also present in considerable numbers, but are easily distinguishable from the Nevadan group.

The earliest of the major Nevadan intrusives is a great plutonic dike of quartz augite diorite (Plate 1, Jqad) which I have called the Redding dike[21]; this body runs through the north central part of the Redding quadrangle into the Shasta district to the north and is more than 25 miles long and a maximum of 2.5 miles wide. The offshoots and isolated bodies are numerous, especially on the west side of the dike, where they cut chiefly the pre-Middle Devonian Copley meta-andesite and the Mississippian Bragdon and Baird formations. On the eastern side, apophyses extend from the main body into the Permian McCloud limestone and Nosoni formation and into the Triassic Pit formation; Diller[22] reports prominent dikes of this rock cutting Middle Jurassic strata on the south slopes of Bagley Mountain in the northeast corner of the Redding quadrangle.

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[20] Crickmay, C. H., op. cit., p. 29.

[21] Hinds, N. E. A., Intrusive Rocks in the Southern Klamath Mountains, California, Bull. Geol. Soc. Amer., vol. 40, p. 170, 1929.

Of probably slightly later age are two chonoliths of sodic granite porphyry. One of these, the Balaklalla chonolith (Plate 1, BC), lies on both sides of the common boundary between the Redding and Weaverville quadrangles west of the Sacramento River; the second, the Bully Hill chonolith (Plate 1, BHC), extends from the Bully Hill mining district in the central part of the Redding Quadrangle eastward into the western part of the Lassen Peak Quadrangle. The Balaklalla porphyry cuts only Paleozoic rocks; the main part of the Bully Hill body cuts Triassic rocks, but certain offshoots and isolated masses intrude Modim strata, the lowest Jurassic of the region. The two porphyries are similar in external appearance, in texture, in mineral and chemical composition, in degree and type of weathering and in extent of hydrothermal alteration. This close resemblance indicates that they were intruded at the same time. No field evidence supports the relative dating of the Redding dike and the granite porphyries, but indirect evidence subsequently presented suggests this relation.

Closely following the rise of the granite porphyry magma came greater floods of somewhat more basic magma which solidified in the southern Klamath Mountains as quartz diorite; to this phase of the Nevadan eruptive cycle belong numerous stocks, bosses, a small batholith, and a host of plutonic and hypabyssal dikes and small irregular bodies. Farther to the north some of the plutonic intrusives are composed of granodiorite rather than quartz diorite.

One stock, the Mule Mountain (Plate 1, MMS), is in contact with the Balaklalla chonolith along its southeastern side. Apparently this contact is intrusive, but so closely did the second magma follow the first that no definite contact can be drawn between the two bodies. A zone in which the granite porphyry is more coarsely crystalline than the normal type and in which the quartz diorite is unusually quartzose, separates the main parts of the two bodies; along this contact it might appear that the granite porphyry forms the salic roof of a huge intrusive and at depth is transitional into the somewhat more basic quartz diorite. Other evidence, however, makes certain the later intrusion of the Mule Mountain stock. To the west of this body and separated from it by a roof pendant of pre-Devonian Copley meta-andesite is the small Shasta Bally quartz diorite batholith (Plate 1, SBB), emplaced apparently at the same time as the Mule Mountain stock and probably continuous at depth with that body. Intruding the roof pendant are dikes of granite porphyry some of which can be traced as offshoots of the Balaklalla chonolith while others are separated from it. In its narrowest part, the rock of the roof pendant has been metamorphosed to chlorite schist, while to the north and south this highly metamorphosed phase passes by gradual transitions into normal, massive meta-andesite. In like manner, the granite porphyry dikes in the narrowest portion of the roof pendant have been converted into quartz sericite schist, while to the northward in the direction of the chonolith the metamorphism is less intense and gradations into the normal massive granite porphyry are present. Thus it is evident that the chonolith and its offshoots antedate both the Mule Mountain stock and the Shasta Bally batholith.

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[22] Diller, J. S., The Redding Folio, U. S. Geol. Surv., Geologic Atlas of the United States, No. 138, p. 9, 1906.

The small Pit River stock of quartz diorite (Plate 1, PRS), almost identical in physical appearance, texture, and mineralogy with the Mule Mountain stock and probably intruded at the same time, transgresses the southern end of the Redding quartz augite diorite dike. The close time relation of the granite porphyry and the quartz diorite stock and the fact that the Pit River stock cuts the Redding dike indicate that the latter body was intruded before the chonoliths.

Other stocks, batholiths, and bosses are present throughout the Klamath Mountain province but most of them cut only Paleozoic and possibly pre-Paleozoic rocks. Certain of these bodies intrude serpentines, but, unfortunately, nothing is known regarding the age of the Klamath serpentines. Classification of these granitoid bodies as Nevadan is not positive, but is strongly indicated by the physical, chemical, and mineralogical similarity of their rocks to those of the Shasta Bally batholith and the Mule Mountain and Pit River stocks whose time of intrusion seems clear. Furthermore, the stage and type of weathering and the degree of hydrothermal alteration are the same in all of these bodies. Indirect evidence thus is strongly in favor of the assumption that they were intruded during a single magmatic epoch. Furthermore, these bodies are distinct in physical characters and mineralogical composition from a group of small granitoid bodies also widely distributed throughout the province which are probably late Paleozoic in age; these are dominantly dioritic and gabbroid and all show extensive recrystallization of their minerals.

Many dikes, sills and small irregular intrusives also belong to various stages of Nevadan intrusive epoch. Some of these intrude the Liassic Modim and the Middle Jurassic Potem beds and débris from them is found in the overlying Cretaceous strata.

Thus the field evidence shows definitely that the Redding dike, the chonoliths of granite porphyry, the Mule Mountain and Pit River stocks, and the Shasta Bally batholith were intruded during the Nevadan folding which involved the Middle Jurassic and all earlier strata in the Klamath province and that probably all of the similar large granitoid bodies throughout the province were intruded during this disturbance.

Regarding the date of orogeny and vulcanism the following evidence is presented. The youngest strata involved in the Nevadan deformation are located in southeastern part of the Klamath Mountains where the number of intrusives is least. Fortunately, however, a few bodies are present which provide highly important evidence relating to the problem. As previously noted, the Bully Hill granite porphyry chonolith intrudes Middle and Upper Triassic Pit (Muschelkalk and Karnic) strata and its apophyses and disconnected offshoots intrude the Upper Triassic (Karnic and Noric) Hosselkuss limestone, the Upper Triassic (Noric) Brock shale, and the Liassic Modim formation. Dikes, petrographically similar to the rock of the Redding quartz augite diorite dike and Nevadan dikes of other petrographic types, cut the Liassic Modim and Ludwigian Potem strata. Thus the folding and intrusion of granitoid magma are definitely post-Potem Middle Jurassic.

Overlying the deeply eroded and steeply dipping beds of this folded complex at the north end of the Sacramento Valley are Lower and Upper Cretaceous formations which are composed largely of detritus carried into advancing oceans from the Nevadan Mountains. In one place only along the contact between the Superjacent and Subjacent series do the Cretaceous strata overlie a Nevadan granitoid intrusive. From about one-half mile west of Igo (a small settlement 12 miles southwest of Redding, county seat of Shasta County) to the North Fork of Cottonwood Creek eight miles farther west; Lower Cretaceous strata were deposited over the Shasta Bally batholith (Plate 1, SBB). At the base of the Cretaceous sequence are local stretches of conglomerate in which abundant boulders of the Shasta Bally quartz diorite embedded in coarse gravel made chiefly of relatively unweathered plagioclase, quartz, and biotite evidently derived from the same body. Elsewhere are coarse arkoses and arkosic sandstones, and a few layers of conglomerate and shale, while at still higher horizons the Lower Cretaceous is dominantly shaley. Lower Cretaceous fossils present at many horizons show that the strata in contact with the batholith range from Middle Paskenta (Valanginian) on the western side to Lower Horsetown (Hauterivian) on the eastern according to information furnished me by Dr. F. M. Anderson[23] who has been making an extensive study of the Cretaceous of the northern part of the Sacramento Valley. From west to east along this contact, younger strata progressively overlap the older.

According to my field assistant, Dr. R. Dana Russell,[24] who mapped and studied the Cretaceous along the contact with the deformed bedrock series in the northwestern part of the Red Bluff quadrangle, pebbles of quartz diorite identical with those of the various Nevadan intrusives are present in various proportions along the contact from Igo to Noble Station, 22 miles to the southwest in the northwestern corner of the Sacramento Valley (Plate 1). Stratigraphically the pebbles are found from the uppermost Horsetown (Barremian) to the basal Paskenta (Infra-Valanginian), that is from the top to the base of the Lower Cretaceous. Whether the Upper Jurassic Knoxville overlies the Klamath complex in this region has not been determined; strata are present in the northwest corner of the Sacramento Valley (Plate 1, JK?) which bear close lithologic resemblance to the Knoxville of type sections farther south, but so far have yielded no fossils.

In the Weaverville quadrangle east of Igo and in the Redding quadrangle, only Upper Cretaceous strata overlie the folded complex. Detritus from Nevadan granitoid bodies, chonoliths, and dikes is abundant in these beds.

Thus field evidence proves that, before the invasion of the earliest Cretaceous seas and subsequent to the Middle Jurassic Potem epoch, the crust in the Klamath region had been folded, intruded by floods of granitoid magma, and deeply enough eroded to expose considerable portions of certain of the granitoid bodies. If strata of Knoxville age overlie the Subjacent Complex, then the deformation occurred between the Middle Jurassic Potem and the late Upper Jurassic Knoxville epoch. Detailed field studies are needed to determine this important point. Certain is the fact that the folding and associated intrusion occurred in late Jurassic time in the Klamath region and that it was accomplished during a single epoch. There is no evidence of two Jurassic deformations such as Crickmay[25] has sought to establish. Unconformities separate the various members of the Jurassic in the southeastern Klamath, but these unconformities are erosional and not angular. Volcanic activity occurred in Liassic Modim time and twice during the Middle Jurassic (Bagley and Potem epochs), but is distinct from that associated with the great orogeny. The dominant magma erupted during the pre-Nevadan Jurassic crystallized as pyroxene andesite and basalt, while the Nevadan magma produced chiefly quartz diorite, granodiorite, and granite porphyry. The Potem and earlier Jurassic volcanics show a considerable amount of recrystallization while the Nevadan rocks exhibit practically none. Also the earlier Jurassic activity produced great volumes of extrusive rocks, while none have been identified as of Nevadan age.

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[23] Anderson, F. M., Personal communication.
[24] Russell, R. Dana, Personal communication.

The data above presented have an important bearing on the age of the granitoid rocks in the nearby Sierra Nevada. Though the Klamath and Sierra Nevada provinces are now separated by an area blanketed with relatively undeformed Cretaceous and later deposits, much of the region during epochs of pre-Nevadan time formed a continuous basin of deposition for either marine, continental, or volcanic deposits. The similarity of many Paleozoic and Mesozoic formations in the Redding district of the southern Klamath and in the Taylorsville district of the northern Sierra Nevada was long ago demonstrated by Diller.[26] The entire region apparently was folded into mountains during the Nevadan deformation. Where the folded trends of the southeastern Klamath pass under the mantle of later rocks, they have approximately the same orientation as those of the northwestern Sierra Nevada where they in turn disappear beneath the southern margin of this mantle. It thus appears that, at the close of the Nevadan orogeny, a continuous belt of mountains extended from Oregon and northern California into the present Sierra Nevada region. These mountains wasted away rapidly, but certain sections were rejuvenated in Cretaceous time. During this period a portion of the belt became a basin of marine deposition, and, in the Tertiary and Quarternary, was further covered by continental sediments and volcanics. Thus was the continuity of the folded belt destroyed, and the Klamath Mountains were isolated from the Sierra Nevada.

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[25] Crickmay, C. H., Jurassic History of North America, Proc. Amer. Philos. Soc., vol. 70, pp. 88 ff., 1931.

[26] Diller, J. S., Geology of the Taylorsville District, California, U. S. Geol. Surv., Bull. 353, 1908.

During this orogeny, granitoid magmas were intruded on a vast scale into the Sierra Nevadan section of the folded crust, and their solidified equivalents have been extensively exposed by subsequent erosion. In a few places granitoid intrusives cut Upper Jurassic Mariposa beds; as previously noted, the Mariposa is late but not latest Jurassic in age. Cretaceous rocks overlie the Nevadan bodies at various localities, but nowhere is this Cretaceous older than the Chico. It thus appears that the folding and igneous invasion in the Sierran Nevada postdates the Mariposa deposition and antedates the submergence beneath Chico seas. Reasoning from the relations previously described from the Klamath Mountains, both events took place before the opening of Cretaceous time.

Since this manuscript was written, N. L. Taliaferro has informed me that his detailed studies of many sections of the Mesozoic formations in the southern Sierra Nevada show that in places the Upper Jurassic Mariposa formation was deposited on moderately flexed beds of probably early Jurassic age. Neither the extent of the folding nor the exact age of the latest strata involved in the deformation have been determined; from evidence now at hand Taliaferro does not consider the folding to have been widespread.

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WORKING FORMULA FOR THE AGE DETERMINATION OF A RADIOACTIVE MINERAL.

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[Presented at the Symposium on the Age of the Earth at the Chicago Meeting of A. A. A. S. in June, 1933.]

Dealing with the solution of any problem, science demands, in the first place, an exact solution consistent with the hypotheses of the problem even though, later, the accuracies of the constants, the physical determinations involved in connection with the gathering of the data, and the difficulties of calculation may indicate that certain approximations are advisable.

In the problem of the determination of the age of a radioactive mineral our hypotheses, universally accepted, are the following:

(1) That the chemical elements originally present in the mineral are the chemical elements that might have been created anywhere and are such as may be found elsewhere.

(2) That the radioactive elements change according to known laws of disintegration and that the constants of disintegration are known.

(3) That the mineral in question has undergone no changes as to quantities of the various constituent parts other than those caused by the radioactive disintegration, i.e., that the mineral is a primary mineral.

(4) That it is possible by chemical and physical analysis to determine the essential data pertaining to the elements concerned in the radioactive disintegration.

Boltwood, who first drew attention to the possibility of the so-called "lead method" of determining the age of radioactive minerals, believed that in primary uraninites all the lead present resulted from uranium disintegration, i.e., that

$$\mathrm{Pb} = \mathrm{RaG} = \frac{\mathrm{U}}{238} \cdot 206 \cdot (e^{\lambda_u \cdot t} - 1)$$

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When Richards, Hönigschmid, Fajans, and others showed that thorium disintegrates into the 208 mass isotope of lead, it then naturally followed that

$$\mathrm{ThD} = \frac{\mathrm{Th}}{232} \cdot 208 \cdot (e^{\lambda_{th} \cdot t} - 1)$$

With the long prevalent idea that the actinium series was obtained as a branch from one of the uranium isotopes, UI or UII, it follows from the displacement law in the periodic table that AcD, the final product of the actinium series, would also be a 206 mass isotope of lead and that it would be formed at the same rate as the RaG. Naturally, then, the AcD as such could be disregarded, for it would be identical with RaG.

In all the early calculations this was done, and, universally also, the presence of ordinary lead was ignored. Various types of formulae were invented on such a basis and the one, perhaps more used than others, is the one giving the age to a first approximation, namely,

$$t_1 = \frac{\mathrm{Pb}}{\mathrm{U} + k \cdot \mathrm{Th}} \cdot C$$

in which k and C were considered constants. It was shown in the National Research Council Bulletin "The Age of the Earth" that if we consider AcD and RaG together and disregard the possibility of the presence of ordinary lead, the correct corresponding expression is

$$t_1 = \frac{\mathrm{Pb}}{\mathrm{U} + k \cdot \mathrm{Th}} \cdot \left[\frac{W_u}{\lambda_u} \cdot \frac{1}{A}\right]$$

in which k is a constant, but C varies somewhat with the atomic weight of the Pb found in the mineral; Wu is the atomic weight of uranium.

It was also shown that if we consider AcD and RaG together and assume no ordinary lead present a simple relation between λ_u and λ_{th} can be obtained in terms of the data obtained from the analysis of the mineral. The relation is

$$\frac{\lambda_u}{\lambda_{th}} = \frac{\mathrm{Th}}{\mathrm{U}} \cdot \frac{206}{208} \cdot \left(\frac{208 - A}{A - 206}\right).$$

Calculating the ratio of the disintegration constants of uranium and thorium by this expression using the data of various minerals, we obtain the values of this ratio as shown in the following table.

Mineral	$\lambda_u : \lambda_{th}$
Thorianite I, Ceylon	3.78
" II, "	3.68
Thorite Brebik, Norway	3.50
Thorianite III, Ceylon	2.91
Cleveite, Saetersdalen, Norway	2.06
Bröggerite, Raade, Norway	1.58
Uraninite, N. Carolina	1.26
Uraninite, S. Dakota	0.76
Cleveite, Aust-Agder, Norway	0.074
Uraninite, Sinyaya Pala, Carelia	0.07

It is evident that $\lambda_u : \lambda_{th}$, a ratio of two constants, should be a constant, but that its values for the different minerals have a very wide range.

Now, if the actinium series were a branch of the uranium-radium series, the explanation would be that in all these minerals there is an appreciable amount of ordinary lead. Since the work of Aston on the isotopic intensities of various radioactive leads shows an amount of the 207 mass isotope of lead greater than could be expected from the 207 mass isotope of ordinary lead, it must be considered almost as a positive proof that some part of this 207 mass isotope of lead is actually actinium D. In the above table, therefore, what would have been supposed to be ordinary lead alone is really ordinary lead plus AcD. We are furthermore forced to conclude that the head of the actinium series is an independent element—which in all probability is an isotope of uranium.

The results of the table show the inadequacy of a formula used for calculating the age, in which formula important consideration is not taken of lead of about 207 mass. Naturally, this should be done by taking into account both actinium D and ordinary lead in building our basic equations.

This was done in the paper in this Journal (1930) in which the following basic principles were used:

I. That the sum of the masses of RaG, AcD, ThD, and ordinary lead, L, is equal to the lead, Pb, found in the mineral by analysis.

II. That the sum of the number of atoms of RaG, AcD, ThD, and ordinary lead, L, is equal to the number of atoms in the lead of atomic weight, A, found in the analysis.

III. That the number of atoms of uranium, actino-uranium, and thorium disintegrating is ultimately the number of atoms formed, respectively, of RaG, AcD, and ThD.

Using the symbols of that paper we arrive at the following equation involving t. The solution of this equation gives us the age.

$$(C - P) \cdot \frac{AcU}{W_{acu}} \cdot (e^{\lambda_{acu} \cdot t} - 1) + (D - P) \cdot \frac{Th}{W_{th}} \cdot (e^{\lambda_{th} \cdot t} - 1)$$
$$+ (G - P) \cdot \frac{U - AcU}{W_u} \cdot (e^{\lambda_u \cdot t} - 1) = Pb \cdot \left(\frac{A - P}{A}\right) \quad \ldots . (I)$$

We also get an expression giving us the amount of ordinary lead, L, namely,

$$L = P \left[\frac{Pb}{A} \frac{AcU}{W_{acu}} \cdot (e^{\lambda_{acu} \cdot t} - 1) - \frac{Th}{W_{th}} \cdot (e^{\lambda_{th} \cdot t} - 1) - \frac{U - AcU}{W_u} \cdot (e^{\lambda_u \cdot t} - 1) \right] \quad \ldots\ldots (II)$$

In these equations, C, D, G, P are the atomic weights of AcD, ThD, RaG, and ordinary lead and similarly W_{acu}, W_{th} and W_u of actino-uranium, thorium, and uranium I; while L, Pb, AcU, Th, and U represent, respectively, the masses in grams of ordinary lead, lead in the mineral, actino-uranium, thorium, and uranium.

If we have also at our disposal the mass spectrograph determinations of the intensities of the lead from the mineral, then in conjunction with similar results for ordinary lead we have also the following equations, in which I_{206}, I_{207}, I_{208} represent the intensities of the 206, 207, 208 mass leads for the lead from the mineral and the numerical coefficients of L, the corresponding values for ordinary lead.

$$I_{208} \cdot Pb = Pb_{208} = ThD + 0.4955\ L$$
$$= \frac{Th}{W_{th}} \cdot D \cdot (e^{\lambda_{th} \cdot t} - 1) + 0.4955\ L.$$

$$I_{207} \cdot Pb = Pb_{207} = AcD + 0.2020\ L$$
$$= \frac{AcU}{W_{acu}} \cdot C \cdot (e^{\lambda_{acu} \cdot t} - 1) + 0.2020\ L.$$

$$I_{206} \cdot Pb = Pb_{206} = RaG + 0.2775$$
$$= \frac{U - AcU}{W_u} \cdot G \cdot (e^{\lambda_u \cdot t} - 1) + 0.2775\ L.$$

Solving each equation for L and taking the mean of the three values we obtain

$$L = \frac{1}{3}\cdot\left[\frac{I_{208}\cdot Pb - \frac{Th}{W_{th}}\cdot D\cdot(e^{\lambda_{th}}-1)}{0.4955} + \frac{I_{207}\cdot Pb - \frac{AcU}{W_{acu}}\cdot C\cdot(e^{\lambda_{acu}\cdot t}-1)}{0.2020} + \frac{I_{206}\cdot Pb - \frac{U-AcU}{W_{u}}\cdot G\cdot(e^{\lambda_{u}\cdot t}-1)}{0.2775}\right] \quad\ldots\ldots(III)$$

This expression can be equated to the value of L obtained from the basic equations and thus obtain an expression involving t, in terms of all known data. The solution of this expression gives accurately the age of the mineral. If the t is obtained otherwise, this expression can serve as a check on the result. It may also be written, of course, in the following simple manner.

$$L = \frac{1}{3}\left[\frac{I_{208}\cdot Pb - ThD}{0.4955} + \frac{I_{207}\cdot Pb - AcD}{0.2020} + \frac{I_{206}\cdot Pb - RaG}{0.2775}\right]$$

= ordinary lead by basic equations

$$= 207.2\left[\frac{Pb}{A} - \frac{AcD}{C} - \frac{RaG}{G} - \frac{ThD}{D}\right] \quad\ldots\ldots(IV)$$

Assuming our hypotheses to be correct, then the solution of either equation I or IV gives us accurately the required age of the mineral.

However, the quantities pertaining to the actino-uranium are derived, not by a direct measurement, as in the case of uranium and thorium but by a more roundabout way. Even so, when the other quantities involved in the calculation are the same, the calculations by Rutherford, by myself, and more recently by v. Grosse give fairly concordant values for the disintegration constant of actino-uranium. This constant comes out about ten times as large as that for uranium I, *i.e.*, the probability of the actino-uranium atoms disintegrating is about ten times as great as that for the UI atoms. This calculation involves, however, the relative activity of the members of the actinium series to that of the members of the uranium-radium series. There exists some discrepancy in the values reported for this activity.

If we assume the result of v. Grosse's recent work that the relative activity at the *present time* in minerals of *any age* is

4 per cent, we readily find by calculation that AcD in minerals, about 1000 million years old, *e. g.*, in such a mineral as the Wilberforce uraninite, is about one-tenth of the RaG (and, of course, somewhat more for older minerals) and that the amount of the actino-uranium is about 0.004 of the uranium present.

Considering some of the uncertainties and the relatively small amount of AcD, question arises whether an approximation cannot be made which would simplify the calculation by eliminating the terms involving the actino-uranium, leaving only those pertaining to the more important uranium and thorium and yet not introduce an error seriously above the error of measurements made in obtaining the data.

Suppose AcD were considered as having an atomic weight 207.2 instead of 206.983 and were considered as initially present (like ordinary lead) in the mineral. What error would be made and what simplification in the calculation could be accomplished?

The number of atoms, c, of actinium D is given by the expression

$$c = (r \cdot \lambda_u \cdot u\ I) \cdot \frac{(e^{\lambda_{acu} \cdot t} - 1)}{\lambda_{acu}}$$

where r = the relative activity ratio, say 0.04.

The true mass of AcD is given by

$$AcD = (r \cdot \lambda_u \cdot \frac{U\ I}{W_u}) \cdot 206.983 \cdot \left(\frac{e^{\lambda_{acu} \cdot t} - 1}{\lambda_{acu}} \right) .$$

The "false" mass, (AcD)′—when atomic weight 207.2 is assumed, would be

$$(AcD)' = (r \cdot \lambda_u \cdot \frac{U\ I}{W_u}) \cdot 207.2 \cdot \left(\frac{e^{\lambda_{acu} \cdot t} - 1}{\lambda_{acu}} \right) \ldots\ldots (V)$$

The fractional error would be

$$\frac{(AcD)' - AcD}{AcD} = \frac{207.2 - 206.983}{206.983} = 0.00105,$$

i.e., about 1/10 per cent.

Now, in the case of the Wilberforce mineral Pb = 9.26 with an error, presumably, about one in the last significant figure, *i. e.*, about 1 in 926 or about the same as the "introduced" error given above. It would seem, therefore, that if we consider AcD with the ordinary lead the error introduced will be of the order of 1/10 per cent if no ordinary lead is present and less than that amount if some ordinary lead is present.

The equations which result from equations I and II above will involve L′, representing ordinary lead plus AcD, and terms involving the uranium and thorium data. The equations are

$$(D-P)\cdot\frac{Th}{232.03}\cdot(e^{\lambda_{th}\cdot t}-1)+(G-P)\cdot\frac{U}{238.14}\cdot(e^{\lambda_u\cdot t}-1)$$

$$=Pb\cdot\left(\frac{A-P}{P}\right).$$

$$L'=L+AcD$$

$$=207.2\cdot\left[\frac{Pb}{A}-\frac{Th}{232.03}\cdot(e^{\lambda_{th}\cdot t}-1)-\frac{U}{238.14}\cdot(e^{\lambda_u\cdot t}-1)\right]$$

......(VI)
......(VII)

Following this assumption it was further shown in the N. R. C. Bulletin "Age of the Earth" that a fairly accurate expression for L′ can be obtained without the knowledge of the age of the mineral. The expression is

$$L'=207.2\cdot\frac{Pb}{A}\cdot\left[\frac{\frac{\lambda_u}{\lambda_{th}}\cdot U\cdot 207.98\cdot(A-206.98)-Th\cdot 205.98\cdot(207.98-A)}{\frac{\lambda_u}{\lambda_{th}}\cdot U\cdot 207.98\cdot(1.22)\,.\,Th\cdot 205.98\cdot(0.78)}\right]$$

......(VIII)

To show the procedure in obtaining the age, t, of a mineral using the equations referred to, I shall take the data for the Wilberforce uraninite which has been analyzed since the publication of the N. R. C. Bulletin. Besides obtaining the age, the disintegration constant of actino-uranium will be calculated and checks obtained for the values of AcD, ThD, and RaG.

$U = 53.52$
$Th = 10.37$
$Pb = 9.26$
$A = 206.195$

Aston's intensities for this lead
$Pb_{206} = 0.859 \cdot Pb = 7.954$
$Pb_{207} = 0.083 \cdot Pb = 0.769$
$Pb_{208} = 0.058 \cdot Pb = 0.537$

v. Grosse's activity ratio = 0.04.

Ruark's calculated atomic masses:

Th : 232.03
U : 238.05
ThD : 207.983
AcD : 206.983
RaG : 205.983

Chemically determined atomic weight of U : 238.14.

λ_u is taken as $1.52(10)^{-10}$ yr.$^{-1}$
λ_{th} is taken as $5.33(10)^{-11}$ yr.$^{-1}$
Note below.

The simplest procedure is to use the approximation formula for L′ (eq. VIII), correcting the amount of lead, Pb, in the mineral by this amount and applying, for example, the exponential formula to get the first approximation age. This being done, the more accurate formula for L′ (eq. VII), involving the age is used and a fairly accurate value of L′ is obtained. Since the t′ by the exponential formula will thus yield a close approximation for the age, it is only necessary to obtain the correction $\Delta t = t' - t$, as derived from the formula (eq. VI) given above and applying this to the value t′ already obtained to get the more accurate value t.

Substituting the data and constants into equation VIII we obtain the approximate value of L′,

$$L' = L + AcD = 0.73.$$

NOTE. The value of Kovarik-Adams for $\lambda_u = 1.53(10)^{-10}$ yr.$^{-1}$ if corrected for the actino-uranium calculated on the basis of 0.04 activity ratio gives $1.51(10)^{-10}$ yr.$^{-1}$ and present work on thorium (not published) indicates that the value for λ_{th} above is more nearly correct than the value obtained from the Ceylon thorianite by calculation.

Using the "exponential formula"

$$t' = \frac{\log\,[U + 0.36\,Th + 1.155(Pb - L')] - \log\,[U - 0.36\,Th]}{6.60(10)^{-11}}$$

we get

$$t' = 1045(10)^6 \text{ years.}$$

The correction for the age is obtained from

$$\Delta t = t' - t = \frac{Q' - Pb \cdot \left(\frac{207.2 - A}{A}\right) \cdot 1.3058(10)^{12}}{U \cdot e^{\lambda_u \cdot t'} - 0.24 \cdot Th \cdot e^{\lambda_{th} \cdot t'}}$$

where $Q' = U \cdot \frac{1.217}{W_u} \cdot (e^{\lambda_u \cdot t'} - 1) - Th \cdot \frac{0.783}{W_{th}} \cdot (e^{\lambda_{th} \cdot t'} - 1)$.

We obtain, then,

$$\Delta t = t' - t \doteq - 1.5(10) \text{ years.}$$

Hence $t = 1046(10)^6$ years, the age of the Wilberforce uraninite.

Using this value of t in equation VII we get

$$L' = L + AcD = 0.746.$$

We have also,

$$RaG = \frac{53.52 \cdot 0.996}{238.05} \cdot 205.983 \cdot (e^{\lambda_u \cdot t} - 1)$$

$$= 7.948$$

$$ThD = \frac{10.37}{232.03} \cdot 207.983 \cdot (e^{\lambda_{th} \cdot t} - 1)$$

$$= 0.532$$

Using Aston's intensities we have

$$\begin{aligned} Pb_{206} &= 7.954 = RaG + 0.2775\ L. \\ Pb_{207} &= 0.769 = AcD + 0.2020\ L. \\ Pb_{208} &= 0.537 = ThD + 0.4955\ L. \end{aligned}$$

The above six equations make it possible to obtain in general a mean value of L and AcD, but in this case it is apparent that the value of L is zero or very nearly so.

Now, equation (V) makes it possible to obtain λ_{acu} provided we know UI or we may write

$$AcD = (r \cdot \lambda_u \cdot \frac{U}{238.14} \cdot 206.983) \cdot (\frac{e^{\lambda_{acu} \cdot t} - 1}{\lambda_{acu}})$$

which gives us $\lambda_{acu} = 1.59(10)^{-9}$ yr.$^{-1}$ with the corresponding half-value period, $T_{acu} = 4.36(10)^8$ yr. With this result we can obtain the expression $0.996\ U = UI$ and by applying it in equation (V) obtain

$$\begin{aligned} \lambda_{acu} &= 1.6(10)^{-9} \text{ yr.}^{-1} \\ T_{acu} &= 4.3(10)^8 \text{ years.} \end{aligned}$$

SUMMARY.

The hypotheses assumed for the solution of the problem of the age of a radioactive mineral have been stated.

Using the lead method and taking into consideration the four types of lead, namely ordinary lead, AcD, RaG, and

ThD, equations which had been previously derived were indicated as giving a correct basis for solution.

To these was added a third equation based partly on the intensities of the isotopic leads in the lead of the mineral and in ordinary lead and on the equation giving the amount of ordinary lead derived from the basic equations. This equation can be used to give correct value of the age or be used to check the value if the age is obtained otherwise.

It was shown that AcD and ordinary lead may be considered as lead of atomic weight 207.2, initially present, without making error of a more serious nature than is obtained from the observational data. On this basis equations having terms for only the uranium and thorium quantities involving time are given.

The following procedure of solution is indicated as best to follow in calculating the age. Calculate the approximate value of $L' =$ ordinary lead plus AcD, using the equation (VIII) giving it as independent of time. Correct the lead of the mineral by this amount. Use the "exponential equation" for the close approximate value of the age of the mineral and then calculate the L' by the more accurate formula (VII) involving the age. Calculate the Δt correction in time by a formula derived from the basic equation and make the correction $t = t' - \Delta t$.

The method was illustrated by applying it to the Wilberforce uraninite and its age was determined as $1046(10)^6$ years.

Following the method of eliminating actinium D plus ordinary lead, as advanced by the author in The Age of the Earth and other publications, gives an age of the Wilberforce mineral which yields calculated values of RaG, ThD, and AcD plus ordinary lead in agreement with the data by Aston on the intensities of the lead isotopes. Incidentally, this agreement shows that the Wilberforce uraninite has either no ordinary lead or an extremely small amount. It should be pointed out that the basic equations used took into account the possibility of the presence of ordinary lead, a fact that cannot be stressed too much in view of the very numerous previous calculations of ages of minerals in which ordinary lead was absolutely ignored.

The disintegration constant of actino-uranium was deduced on the basis of 4% actinium series relative activity to uranium-radium series and the disintegration constant was found $\lambda_{acu} = 1.6(10)^{-9}$ yr.$^{-1}$, corresponding to the half-value period $T_{acu} = 4.3(10)^8$ yr.

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THE PROBABLE ERROR OF SAMPLING SEDIMENTS FOR MECHANICAL ANALYSIS.

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INTRODUCTION.

The probable error of sampling sediments for mechanical analysis has received but little attention from sedimentary petrologists. It has long been recognized that sampling errors are involved in any study of sediments, but no quantitative investigation of their magnitude has been made to the writer's knowledge. Wentworth[1] mentioned such errors in his consideration of the accuracy of mechanical analysis, but he made no attempt to evaluate them beyond pointing out that they were "large and unknown." Soil scientists[2] have paid considerable attention to the subject from their own point of view, and it is the purpose of the present paper to describe the application of similar methods to sediments, so that some quantitative data may be made available to workers in the field.

The errors of mechanical analysis may be divided into several types. There is first the sampling error, which is a function of the homogeneity of the sediment, of the precise locality in which the sample is collected, and of the manner in which it is collected. In the laboratory, there is a splitting error involved in reducing the field sample to a test sample, and a sieving error involved in the actual analysis of the test sample. Wentworth studied the two latter errors quantitatively in the paper mentioned above. Elsewhere[3] he listed all the errors that may enter the mechanical analysis of sediments, but for the purposes of the present paper only those mentioned here will be considered. Indeed, for the determination of the sampling error alone, it is sufficient that the two latter errors be combined into a single "laboratory error" in contrast to the "field error."

It is important to recognize that the errors mentioned above are independent of each other, and that therefore they may be individually determined. Thus, if a series of related samples are separately analyzed, the results are influenced by all three errors. If a composite sample is prepared from equal amounts of the separate samples, and analyzed, the splitting and sieving errors are still present, but the sampling error is reduced to zero, since only one sample is now involved. Similarly, if a single split of the composite sample is repeatedly analyzed, the only error remaining is the sieving error. This independence of the errors is used in their evaluation.

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[1] Wentworth, C. K., The accuracy of mechanical analysis: This Journal, 13, 399-408, 1927.

[2] Robinson, G. W., and Lloyd, W. E., On the probable error of sampling in soil surveys: Jour. Agric. Sci., 7, 144-153, 1915-16. Also: Post, A. H., Soil variability as determined by statistical methods: Soil Science, 17, 343-357, 1924.

[3] Wentworth, C. K., Methods of mechanical analysis of sediments: Univ. Iowa Studies in Nat. Hist., 11, No. 11, p. 33, 1926.

When only one error is involved in a particular study, such as in the repeated analysis of a single test sample, the observed error equals the actual error. When two or more independent errors are involved, they do not combine as simple arithmetic sums, but obey a more complex law. That is, the observed error E is not the sum of the independent errors $e_1, e_2, \ldots e_n$, but it is the square root of the sum of the squares of the independent errors:[4]

$$E = \sqrt{(e_1)^2 + (e_2)^2 + \ldots + (e_n)^2} \qquad \ldots\ldots(1)$$

In the preceding use of the word "error" the standard deviation is meant, which is also referred to as the "standard error" by some writers. The standard deviation is a useful measure of the departure of an observation from the mean value, but a more convenient measure of this departure is the probable error, which is closely associated with the standard deviation. Equation (1) applies equally well to the probable error, and in the following pages the word "error" is to be understood as referring to the probable error.

It may be well at this point to review the meaning of the statistical terms used, so that the following discussion may be free of ambiguities. The arithmetic mean M of a set of N observations $x_1, x_2, \ldots x_n$, is calculated by adding all the observations and dividing by their number:

$$M = \frac{\Sigma(x_i)}{N} \qquad \ldots\ldots(2)$$

where x_i refers to the individual observations and Σ refers to the process of summation.

The standard deviation is calculated by taking the difference d of each observation from the mean, squaring it, and adding all the squared terms together. This total is divided by the number of observations, and the square root of the quotient is extracted. The standard deviation, σ, is thus the square root of 1/N-th of the sum of the squared deviations from the mean:

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[4] Fisher, A., The mathematical theory of probabilities, New York, 1, p. 106, 1915.

$$\sigma = \sqrt{\frac{\Sigma\,(d^2)}{N}} \qquad \ldots\ldots(3)$$

The probable error, according to Mills,[5] is that amount which, in a given case, is exceeded by the errors of one-half the observations. The name of the measure is derived from the fact that the probability that a given observation will vary from the mean of all observations by an amount greater than the probable error, is exactly 1/2. If the probable error of an observation is 3 per cent, for example, the chances are even that it will be smaller or larger than the mean by an amount equal to three per cent of the mean value. Since the most probable value of a set of observations in a normal frequency curve is their mean, the probable error is always measured from the mean. When the deviations from the mean constitute a normal frequency distribution, the probable error bears the following relation to the standard deviation:[6]

$$\text{P.E.} = 0.6745\,\sigma \qquad \ldots\ldots(4)$$

In the present discussion it is assumed that the errors are fluctuations about a true average value, and that on the whole the number of deviations in one direction is the same as those in the other. When this assumption is satisfied, the probable error becomes the most important device available as an index of the reliability of quantitative measurements.

In the examples of sampling errors that follow, the general form of equation (1) is simplified to the following, where E is the total observed error, e_1 is the sampling error, and e_2 is the total laboratory error, as defined earlier:

$$E = \sqrt{(e_1)^2 + (e_2)^2} \qquad \ldots\ldots(5)$$

APPLICATION OF METHOD TO BEACH SANDS.

Among sediments generally considered to be quite homogeneous are beach sands, and it may reasonably be expected that the sampling error involved should be small. In order to apply the technique to an actual case, 24 samples[7] were collected from the southern end of Lake Michigan, at Waverly Beach, about 10 miles west of Michigan City, Indiana. The samples were collected from the beach in accordance with a predetermined grid pattern. They were spaced as shown in figure 1. The outermost samples were taken about 8 feet from the water line, at intervals of 60 feet along the shore. On a line with each of these points, samples were taken at distances of 30 and 60 feet from the shore. The beach is about 75 feet wide along most of the sampling distance, as shown by scattered flat pebbles at the surface. Farther inland, a veneer of wind-blown sand covers the beach to varying depths.

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[5] Mills, F. C., Statistical methods, New York, pp. 160 ff., 1924.

[6] Mills, F. C., loc. cit.

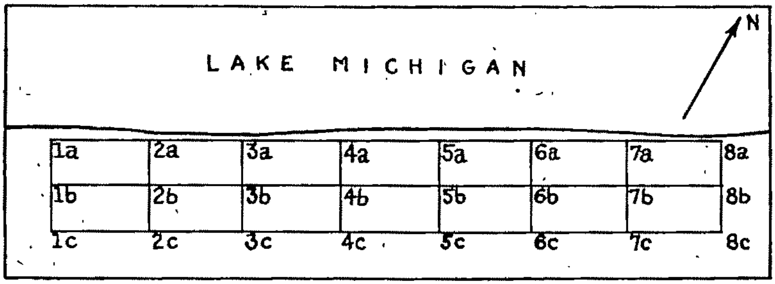

Fig. 1. Grid pattern for Waverly samples.

In collecting the samples, a corrugated downspout pipe 14 inches long and measuring 2 to 2½ inches in diameter[8] was forced down to a depth of 8 inches in the sand. The core thus formed was withdrawn and preserved in a double Kraft paper bag. In examining the cores it was noted that some of the samples had rather coarse sand more or less uniformly distributed through them, and in others the coarse material was concentrated in layers of varying thickness, often near the bottom of the core.

[7] It is not necessary to study sets of 24 samples to determine the sampling error, but it is clear that within limits the greater the number, the greater the accuracy of the determination. An approximate value may be found by using sets of 8 samples, but the results will be only about half as accurate as when 24 samples are used. The number 8 is arbitrary, but with a recognition of its limitations, it may be used in obtaining a first approximation to the value of the error.

[8] This device was developed by G. H. Otto, who kindly loaned it to the writer.

In the laboratory each sample was split into a test sample weighing from 30 to 40 grams, and separately analyzed, by sieving for ten minutes in an automatic shaker. In addition, 50 ± 1 grams were split from each field sample, and combined into a single composite sample. Eight test samples were split from the composite, and separately analyzed.

It is clear from the earlier discussion that the 24 individual analyses include both the sampling and laboratory errors, while the analyses of the composite sample include only the laboratory error. The results of the 24 individual analyses and those of the 8 composite analyses are shown in Table I.

TABLE I. Weight Percentages of Waverly Samples.

Sample	Above 1 mm.	1 mm. to .701	.701 to .495	.495 to .351.	.351 to .246	.246 to .175	.175 to .124	.124 to .088	Medians
1a	0.1	0.3	3.0	18.9	51.7	22.6	3.1	0.3	0.290
1b	1.1	0.8	4.4	16.3	43.0	23.3	10.9	0.2	0.278
1c	tr	0.1	0.4	4.3	40.7	46.9	7.4	0.2	.238
2a	0.2	0.6	2.9	15.7	50.3	26.4	3.6	0.3	.281
2b	tr	0.4	2.8	13.5	45.5	32.7	4.9	0.2	.270
2c	0.2	0.9	5.0	12.4	44.3	32.8	4.1	0.3	.272
3a	..	tr	0.3	11.0	55.9	24.7	7.9	0.2	.273
3b	tr	0.2	1.1	7.1	44.0	40.1	7.3	0.2	.251
3c	tr	0.4	2.3	10.1	44.6	31.5	10.8	0.3	.261
4a	..	tr	0.3	12.2	49.0	32.7	5.5	0.3	.266
4b	0.1	0.3	0.3	3.2	39.3	44.8	11.6	0.4	.234
4c	tr	0.2	1.9	13.1	49.6	24.3	10.7	0.2	.272
5a	..	tr	0.7	12.8	46.5	34.3	5.6	0.1	.263
5b	..	tr	0.2	3.3	42.5	45.9	7.7	0.4	.240
5c	tr	0.1	1.3	11.7	49.5	32.4	4.8	0.2	.270
6a	..	tr	1.0	10.2	43.1	35.0	10.6	0.1	.254
6b	tr	tr	0.2	4.9	41.7	42.3	10.6	0.3	.240
6c	tr	0.4	2.6	14.3	48.5	25.4	8.6	0.2	.277
7a	tr	0.7	4.2	15.2	43.7	29.4	6.6	0.2	.273
7b	0.2	1.0	2.5	5.6	36.9	44.6	8.8	0.4	.239
7c	0.2	0.5	2.7	11.9	42.8	34.4	7.2	0.3	.262
8a	0.4	1.0	6.4	27.3	45.5	17.2	2.2	..	.310
8b	..	tr	0.7	9.3	50.0	31.3	8.4	0.3	.263
8c	tr	0.1	1.2	9.7	49.0	32.9	6.9	0.2	.262
Average	0.1	0.3	2.0	11.4	45.8	32.8	7.3	0.3	.264
Analyses of Composite Sample	0.2	0.3	2.0	11.4	43.2	37.0	5.7	0.2	.260
	0.1	0.2	2.1	11.3	44.2	36.3	5.5	0.3	.262
	0.2	0.5	2.0	11.2	44.7	34.4	6.7	0.3	.262
	0.1	0.3	2.2	11.2	42.2	38.2	5.5	0.3	.259
	0.3	0.4	2.0	11.4	42.4	38.0	5.3	0.2	.260
	0.2	0.4	1.9	11.6	46.5	30.4	8.7	0.3	.266
	tr	0.4	1.8	11.3	42.8	37.8	5.5	0.4	.260
	0.1	0.3	2.0	10.9	44.8	35.4	6.2	0.3	.261
Average	0.1	0.4	2.0	11.3	43.9	35.9	6.1	0.3	.261

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In order to determine the deviations among the samples, several choices of variable are available for computation: (a) the deviation of each grade size about its mean, (b) the deviation of some average grain size about its mean, (c) the deviation in some statistical value, as the quartile deviation, or (d) the deviation in the degree of sorting. In the present paper the deviations about the median grain size will be computed, to illustrate the method. The median is being increasingly accepted as an average grain size, and such a study will indicate the variation of the average grain size due to sampling errors. The medians of the samples, as determined from cumulative curves, are included in Table I.

To avoid confusion it should be pointed out that the probable error is always computed with reference to the arithmetic mean, and in the present case these deviations will be measured about the arithmetic mean of the median values. The median is thus the variable under consideration, and the problem is to determine the extent to which it fluctuates about its own average value.

Reference to Table I will indicate that the mean value of the 24 medians, calculated with equation (2), is 0.264 mm. The individual values vary from 0.234 to 0.310 mm. The greatest positive deviation is + 0.046 and the greatest negative deviation is — 0.030. The standard deviation, calculated from equation (3), was found to be 0.0177:

$$\sqrt{\frac{\Sigma(d^2)}{N}} = \sqrt{\frac{0.007456}{24}} = \sqrt{0.000311} = 0.0177.$$

By using equation (4), the probable error was found to be 0.0120. By taking the ratio of this probable error to the mean value of the median, the relative error is found to be 0.0455 = 4.55 per cent. This is the value of E in equation (5), expressed as a percentage. It is the total observed error, including as it does the sampling and laboratory errors.

The mean value of the medians of the composite sample is 0.261 mm. The values vary from 0.259 to 0.266 mm. The standard deviation of this set about its mean value is 0.002:

$$\sqrt{\frac{\Sigma(d^2)}{N}} = \sqrt{\frac{0.000034}{8}} = \sqrt{0.000004} = 0.002.$$

By equation (4) the probable error is found to be 0.0014. This is 0.54 per cent of 0.261, the mean value. The value 0.54

is the value of e_2 in equation (5), also expressed as a percentage. By substituting the values in the equation, e_1 may now be found. This is most conveniently done by squaring both sides of the equation. Then $E^2 = (e_1)^2 + (e_2)^2$, or

$$\begin{aligned} 20.7 &= (e_1)^2 + 0.3 \\ (e_1)^2 &= 20.4 \\ e_1 &= 4.51 \text{ per cent.} \end{aligned}$$

Thus the sampling error is about 8 times as large as the laboratory error. It is relevant at this point to inquire whether the sampling or laboratory errors are constant for any type of sediment. To determine this, a set of 8 samples was collected at 100-foot intervals from the Lake Michigan beach at Manitowoc, Wisconsin, and analyzed in the same manner as the Waverly samples. The total observed error was found to be 1.52 per cent, the sampling error was 0.75 per cent, and the laboratory error, 1.32 per cent. Thus it appears that both errors are variables, but it may reasonably be expected that there is a limited range of error in any single type of sediment. Thus, if the ranges of error among various kinds of sediments were sufficiently well known, it is conceivable that in a sediment of unknown origin the magnitude of the sampling error would furnish a clue to its origin.

It is possible now to determine the extent to which the median value of a random sample must be corrected to allow for the sampling error. For this purpose we may consider the Waverly set, which has the larger error. Since the probable sampling error of the set is 4.51 per cent, that means the chances are even that a single observation will be either larger or smaller than the true median value by 4.51 per cent. This percentage of 0.264 is 0.012. Thus the chances are even that the median of a random sample lies within the range of 0.252 and 0.276 mm. The effect of the laboratory error, computed on the same basis, is that the median of the random sample lies between 0.263 and 0.265 mm. Thus the laboratory error is quite negligible. The total error to which the median of a random sample is subject is 4.55 per cent. This yields essentially the same range as the sampling error. Hence the absolute deviation of the median from the true value, on the basis of equal probabilities, is ±0.012 mm.

Whether an error of this magnitude is serious or not depends on the variation of the medians among samples collected at appreciable intervals. Thus, if a study involves samples collected at intervals of a mile, and if the variation of the median value among successive samples is several times the value of the probable error, then the probable error has no serious effect on the medians of the random samples. On the other hand, if the variation among the samples is of the same order of magnitude as the probable error, then it would be difficult to determine whether the fluctuations are due to the sampling error or to variations along the beach.

If the combined error or either of the independent errors is larger than convenient, they may be reduced to any desired value. To understand the method used in reducing the errors, it should be borne in mind that the probable error thus far discussed refers to the probable error of a single random sample. Thus in the present case the median value of a single sample will have an even chance of varying not more than ±4.55 per cent from the true mean value of the median. Thus it may be said that the probable error of the mean for a single sample is ± 4.55 per cent. Now the probable error of the mean varies inversely as the square root of the number of samples involved:[9]

$$PE_m = \frac{.6745\,\sigma}{\sqrt{n}} \qquad \ldots\ldots(6)$$

Following Robinson and Lloyd[10] it will be assumed that the probable error of the mean of a combined error is equal to the square root of the sum of the squares of the probable errors of the independent means. This is merely an extension of equation (5), and yields:

$$PE_m = \frac{E}{\sqrt{n}} = \frac{\sqrt{(e_1)^2 + (e_2)^2}}{\sqrt{n}} \qquad \ldots\ldots(7)$$

where n is the number of cases included. In a random sample, n = 1. If, however, the single sample is analyzed twice, the sampling error is still the same, but the laboratory error is reduced, and the total error becomes

$$\sqrt{(e_1)^2 + \left(\frac{e_2}{\sqrt{2}}\right)^2}.$$

Similarly, by mixing two closely spaced samples into one composite before analysis, and analyzing the composite only once, the laboratory error will remain the same, but the sampling error is reduced, and the total error becomes

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[9] Mills, F. C., op. cit., p. 555.
[10] Loc. cit.

$$\sqrt{\left(\frac{e_1}{\sqrt{2}}\right)^2 + (e_2)^2}.$$

The extension to the general case is obvious, in which n samples are mixed into one composite, and the composite is analyzed n times.

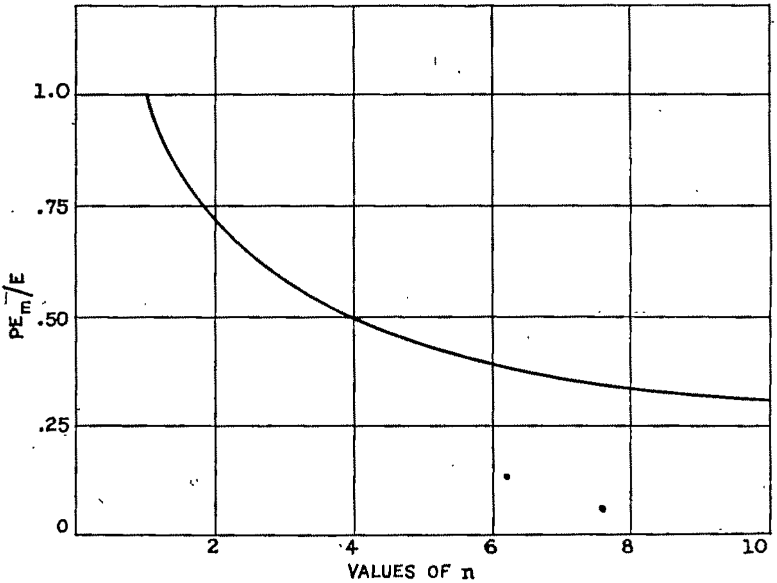

Fig. 2. Graph of the function $PE_m/E = 1/\sqrt{n}$.

In the present case the laboratory error is negligible, and the sampling error is 4.51 per cent. A simple example will indicate how the total error varies in accordance with the preceding discussion. If 3 closely spaced samples are combined into a composite and analyzed once, the total error becomes

$$\sqrt{\left(\frac{4.51}{\sqrt{3}}\right)^2 + (0.54)^2} = 2.66 \text{ per cent.}$$

Thus the error has been cut almost in half. By substituting values for n from 1 to any desired number, we may determine how the error varies as more and more samples are combined into a single composite. It will be interesting to consider the general case, and to determine how the total error varies as n increases. It is convenient to plot the remaining total error as a fraction of the original total error of a single random sample. By dividing equation (7) through by E, we obtain $PE_m/E = 1/\sqrt{n}$, which is a hyperbola asymptotic to the X- and Y-axes. By substituting values for n, corresponding values for PE_m/E may be found, as shown in Table II. Figure 2 illustrates the curve. It will be seen that the curve flattens appreciably after $n = 4$ is reached, at which point $PE_m/E = 0.500$. Thus a composite of 4 samples will reduce the original error of a single random sample to one-half its value.[11] The decrease in the rate of descent may be seen from the fact that when $n = 10$, PE_m/E has dropped only to 0.316.

TABLE II.

Values of PE_m/E and n from $PE_m/E = 1/\sqrt{n}$.

n	1	2	3	4	5	6	7	8	9	10
PE_m/E	1.00	0.707	.577	.500	.447	.408	.378	.354	.333	.316

It may be concluded from the preceding discussion that there are two ways in which cognizance may be taken of the sampling errors. As a concrete example, consider a study of the variations along a stretch of beach 50 miles long. Samples are to be collected at intervals of two miles over this distance. These principal samples may be referred to as serial samples. If a single sample is collected at each serial point, then every analysis is affected by the total sampling error of a random sample. The curve of figure 2 shows that this sampling error may be reduced to one-half by collecting 4 closely spaced samples at each of the serial points, and combining them into a composite sample. This will furnish no clue to the magnitude of the sampling error, but the worker will be assured that whatever the error is, it enters his results to only half the extent that it would if single random samples were collected. It is difficult to recommend any fixed interval in the spacing of the sets of samples for the composite at each serial point. However, in the example given, the 4 samples may be collected

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[11] In order that the *total error* be reduced by one-half, the composite of 4 samples must be analyzed 4 times. If the composite is analyzed only once, the *sampling error* is reduced by one-half, while the laboratory error remains constant. It should also be mentioned that for small values of n the equation of Figure 2 may not hold precisely, but the resulting curve is sufficiently accurate for present purposes.

25 or 50 feet apart, because the ultimate test is to see that the distance between the samples of any composite is very small in contrast to the distance between the serial points.

A more detailed study, involving the determination of the sampling error itself, may be made by collecting random samples at the serial points, and supplementing these with sets of 8 closely spaced samples, at about every third or fourth serial point. The probable error may be determined for each of these sets as described earlier. The values obtained will indicate the magnitude of the sampling error at several points along the beach, and from these data it will be possible to determine whether the error is appreciable in terms of the deviations among the serial samples themselves. In addition, the serial samples may be corrected in accordance with the value of the nearest probable error. By combining the two suggested sampling techniques, not only will the probable error of a random sample be known, but it will be reduced to half its value in the composite serial samples.

SUMMARY.

The present paper shows that it is possible to compute the magnitude of the sampling error independently of the other errors involved in mechanical analysis. In the examples chosen, the probable error of sampling beach sands varies from 0.75 to 4.51 per cent. Thus even in a single type of sediment, the error may be a variable. It is also shown that the sampling error could be reduced to any desired value by composite samples, and that a composite of four closely spaced samples reduces the error of a single random sample by half. In practice, the effect of the probable error of sampling on a study of variations among beach sands depends on the relation between the size of the probable error and the amount of variation among successive samples of the series under study. Finally, it is mentioned that with sufficient knowledge of the range of errors among various types of sediments, it may be possible that the magnitude of the error in a particular case will furnish contributory evidence to the origin of the sediment.

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THE GEYSER AREA NEAR BEOWAWE, EUREKA COUNTY, NEVADA.[1]

T. B. NOLAN AND G. H. ANDERSON.

The existence of a geyser area near Beowawe, Nevada, was called to the attention of one of the writers early in 1932 by Dr. E. T. Allen of the Geophysical Laboratory. On August 26 of the same year, in the course of other field work in northern Nevada, both writers visited the area and spent a few hours studying it. The geysers are found within a small area, probably less than a quarter of a square mile in extent, about 6 miles by auto southwest of Beowawe, a station on the main lines of the Southern Pacific and Western Pacific railroads (Figure 1). The newly constructed Victory Highway, the main route for transcontinental auto traffic in Utah and Nevada, is about 10 miles north of Beowawe, a well maintained dirt road connecting the two.

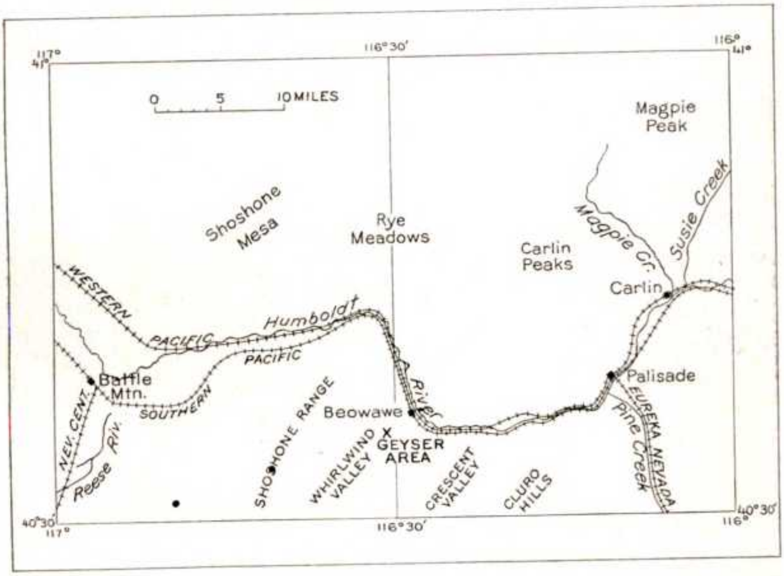

Fig. 1. Index map of a portion of Nevada, showing location of geyser area.

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[1] Published by permission of the Directors of the U. S. Geological Survey and the Nevada State Bureau of Mines.

Although the area is thus easily reached from both the railroad and the highway, the existence of the geysers appears to be almost unknown even to many residents of the nearby country. The thermal activity was first described at the time of construction of the Central Pacific railroad by A. S. Evans[2] in a popular article, parts of which were quoted by Peale.[3] No later references to the region are known.

The writers are indebted to Doctor Allen, and to James Gilluly of the Geological Survey, for criticism of the manuscript.

Plate I. Whirlwind Valley, looking north-northwest from geyser area.

Geologic Setting.

The small area in which the geysers are found is on the southeastern border of Whirlwind Valley, a northeasterly trending valley which drains the northern end of the Shoshone Range and empties into Humboldt River. For about 10 miles southwest of the Humboldt, the alluvium-filled valley is wide and flat-floored (Plate 1). At least locally in this portion of the valley, the ground water level is near the surface, as shown by the vegetation.

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[2] Evans, Albert S., In Whirlwind Valley: The Overland Monthly, **2**, San Francisco, 1869.

[3] Peale, A. C., The thermal springs of Yellowstone National Park: U. S. Geog. Sur. Terr. Ann. Rept. 12, pt. 2, pp. 322-323, 1883.

The rock ridges on either side of the valley are shown on the maps of the Fortieth Parallel Survey to be underlain by lava flows which "consist in general of fine grained dolerite, made up of plagioclase, augite, olivine, and magnetite, with more or less of a gray globulitic base. Through these doleritic tables break out a great number of vertical dikes of fine-grained anamesitic basalt, containing a high proportion of brown glass, giving a very resinous lustre to the fresh fracture."[4] The rock exposed in the vicinity of the geysers is probably similar to the basalts found by Hague and Emmons; it is a reddish purple porphyry in which phenocrysts of fresh plagioclase are moderately abundant. These are microscopically zoned and many have a composition close to calcic andesine, but some at least appear to be oligoclase. Completely altered phenocrysts of olivine are smaller and less abundant. The groundmass of the rock appears to have consisted originally of small laths of plagioclase in a glassy matrix, but the glass is now recrystallized, and the rock is invaded by irregular veinlets of a mineral that is probably tridymite.

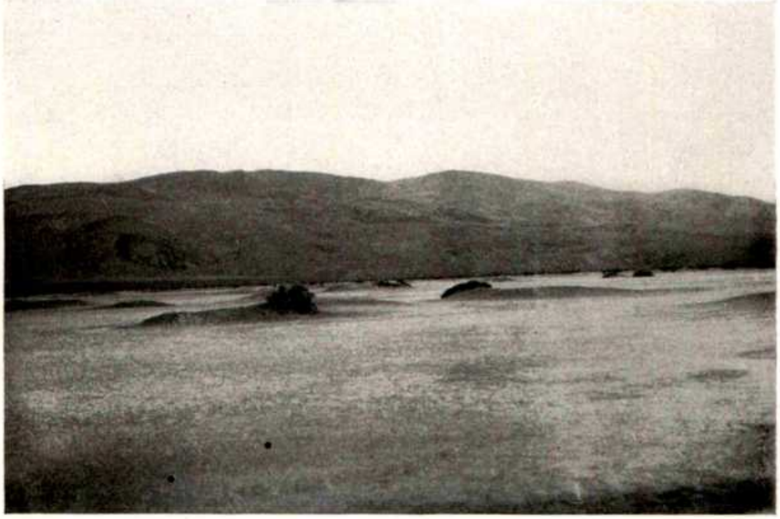

Plate 2. Landslide topography east-northeast of geysers.

[4] Hague, A., and Emmons, S. F., U. S. Geol. Expl. 40th Par., **2**, p. 618, 1877.

The contact between the lavas and the valley fill is abrupt and notably linear along the southeastern side of Whirlwind Valley and transgresses the strike of the slightly tilted lavas. It probably represents one of the Basin Range faults. About 2 miles northeast of the geysers the straight front of the hills is broken by a lobate extension of low and irregular hills into the valley. The hummocky topography of this protrusion extends back to the head of the ridge, where it abuts against cliffs. (Plate 2.) Although this area was not examined except from the valley, it appears from there to be a large landslide.

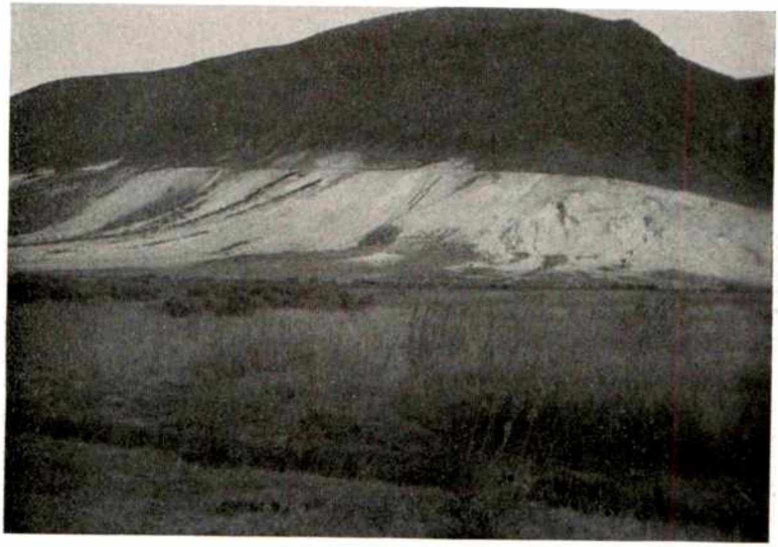

Plate 3. The sinter terrace on which the geysers are located, looking east from Whirlwind Valley. Remnants of old sinter may be seen on the slope above the terrace.

Thermal Activity.

The thermal activity in the region is largely restricted to the surface of a sinter terrace (Plate 3) about half a mile long, 100 feet or less in width, and 200 feet above the valley fill. Some pulsating hot springs, however, are found on the valley floor at the foot of the terrace (Figure 2). Geysers are the most spectacular features of the sinter terrace, although they are much less numerous than fumaroles. Hot springs are also moderately abundant.

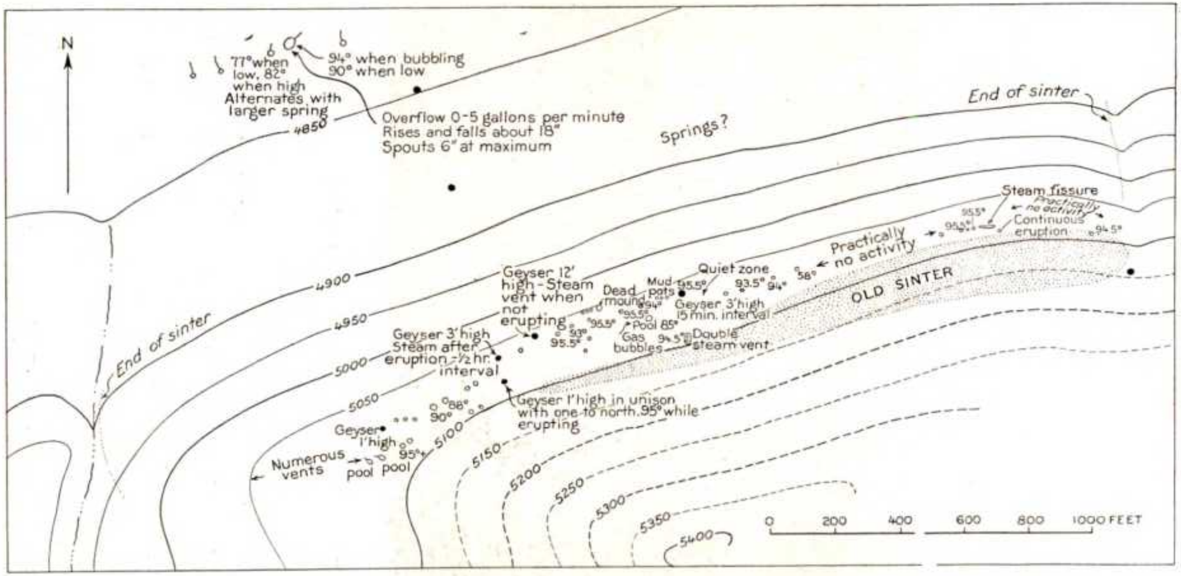

Fig. 2. Sketch map of geyser area near Beowawe, Nevada.

Although the terrace (Plate 4) is composed chiefly of sinter, it is clear that in several places blocks of basalt from the steep slopes above have fallen on the terrace and been covered by sinter. In several of the vents it is possible to examine the terrace material to a depth of several feet, and in such places the sinter persists to the lowest point observable. Near the northeast end of the terrace, there are remnants of an old porous sinter deposit on the slope above. These are considerably dissected and show by their layering that the sinter has been built up by the accretion of material rather than by the alteration and leaching of the lava. The layers are slightly tilted. This occurrence of old sinter above the level of the present terrace suggests that there has been renewed movement along the fault that forms the boundary between ridge and valley.

Plate 4. Surface of the sinter terrace. A small geyser is playing in the background.

The siliceous sinter composing the terrace is almost entirely made up of opal. It varies considerably in appearance and texture from place to place. The material now forming on the terrace is somewhat cavernous and light gray to white in color. Locally a layered texture is apparent due in part to slight differences in color or granularity of the opal, and in part to the presence of films of blue-green algae, which have preserved their color despite covering by opal. In most specimens, however, the subsurface portion of the sinter consists of an aggregate of opal fragments, which are only partially cemented. The smooth surface of the sinter is commonly a brilliant white dense opal, with locally a suggestion of iridescence. In a few places, this smooth surface is covered with tiny protuberant masses of opal about 1 mm. in diameter. Sporadic quartz grains and aggregates of clay minerals are found in the sinter locally, together with small quantities of carbonates and sulphates of sodium and calcium. Some of the carbonate is relatively insoluble in hot water. The old sinter on the ridge above the terrace appears to be similar to that now being formed, except for the greater abundance of clay minerals, and a common staining by iron oxides. At the western end of the exposure shown on Figure 2 no layering was observed and this material may be thoroughly leached and altered lava.

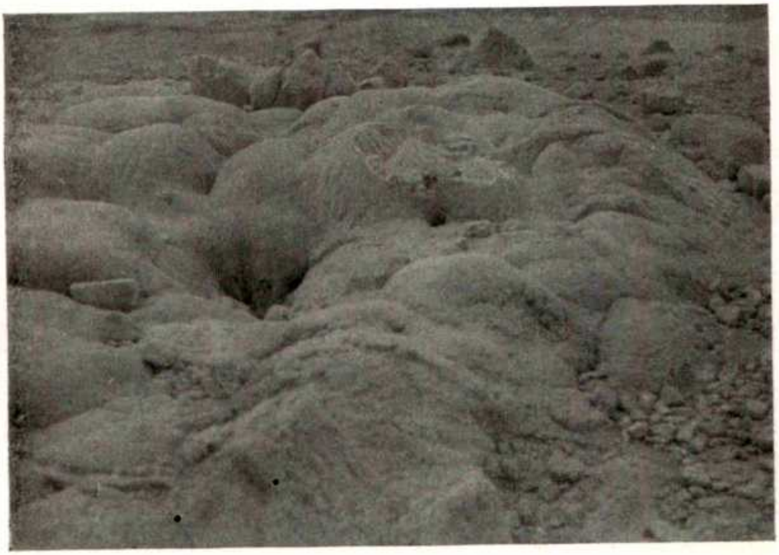

Plate 5. Sinter mound built around geyser, showing mamillary character of the sinter.

Sinter mounds have been formed around all of the active geysers (Plates 5 and 6), and there are a few mounds around vents that appear to be no longer active. The mounds are commonly a foot or less in height but some reach a height of more than 3 feet. The mounds are composed of rounded or mamillary masses of glassy opal which on fresh fractures has a faintly pinkish tinge. The sinter masses show a pronounced tendency to fracture normal to the faint banding which is parallel to their outer surfaces.

Geysers.—At the time of visit only three geysers were noted that erupted to a height of more than a foot. Mr. F. R. Garnett, of Beowawe, however, reports that during the winter there is increased activity; Evans' descriptions, based upon a visit made late in the winter, also indicate that the geysers are both more abundant and play to greater heights in winter than at the time of our examination. This apparent seasonal variation is perhaps caused by an increase in the amount of ground water available in the winter. The absence of sinter mounds around many of the fumaroles suggests, however, that relatively few of the vents actually show a seasonal change from fumarole to geyser.

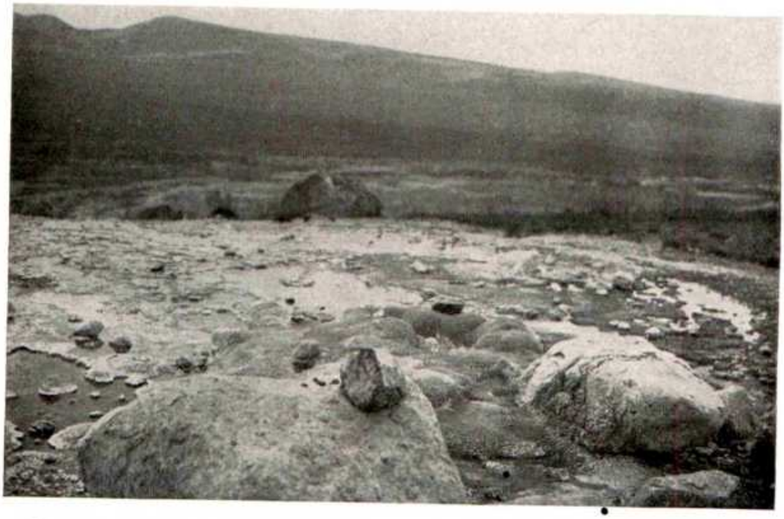

Plate 6. Sinter terrace and sinter mound. The large blocks are of lava from the slopes above the terrace and are coated by sinter.

Two of the active geysers observed by us played to a height of about 3 feet (Plate 7) and the third to about 12 feet. In all three the eruption lasted about a minute and the quiet interval between eruptions from 15 minutes to half an hour, although in no case were accurate time measurements made. All three of the larger geysers are fumaroles throughout most of the interval between eruptions, the steam having a temperature of about 95.5° C., which is approximately the boiling point of water for this altitude. In a few places, for example 200 feet west of the more easterly 3-foot geyser, there are sinter mounds from which no steam escapes at present. These may reflect a decreasing thermal activity in the region, but the abundance of other vents in the immediate vicinity suggests, on the other hand, that the dead mounds are the result of choking or filling of the channels through which the steam formerly reached the terrace surface.

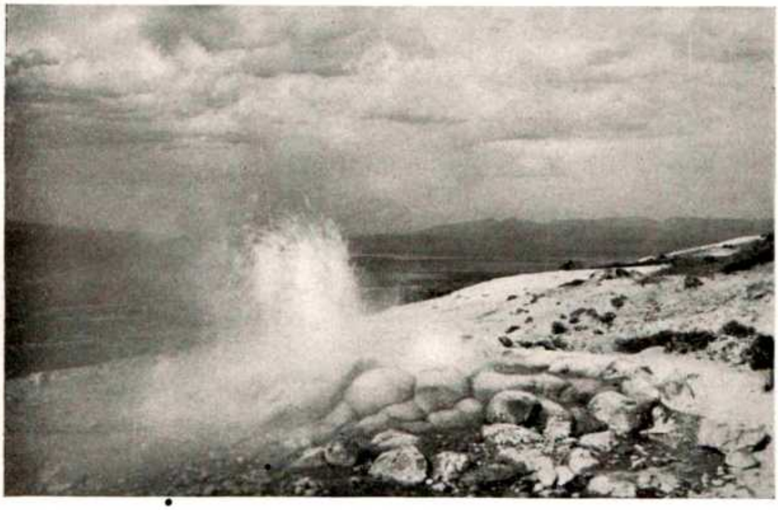

Plate 7. The more westerly 3-foot geyser in eruption.

Fumaroles.—The total number of fumaroles present on the terrace was not determined, but there must be considerably more than a hundred, a large proportion of which are concentrated in the western half of the terrace. Many of these, however, are small, closely spaced vents that are probably supplied with steam from a single trunk channel. This is certainly the case near the eastern end of the terrace, where there is a linear series of closely spaced vents, one of which, a narrow fissure about 2 feet long, probably represents a portion of the trunk channel that has escaped filling by sinter.

Most of the fumaroles issue directly from the surface of the terrace, but several of the larger ones issue from sinter mounds similar to those from which the geysers erupt, and it is probable that these vents at times of more abundant ground water, are the sites of geysers also. The open conduits supplying the fumaroles must be rather tortuous, since in the several vents tested, it was not possible to reach depths of more than 6 or 8 feet with a steel encased thermometer supported by copper wire.

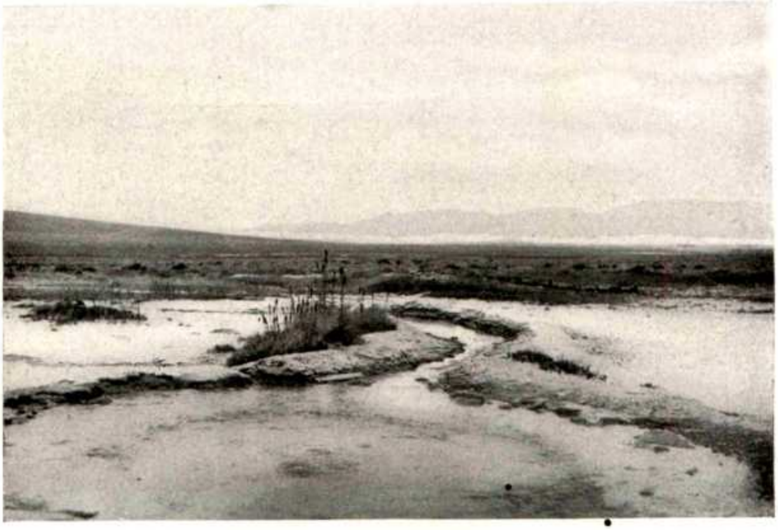

Plate 8. Intermittent spring at base of terrace. Intermediate stage. Gas bubbles rising in center of pool.

No superheated fumaroles were found, all of the measurements that were made showing a temperature of 95.5° C.

Hot springs.—At several places on the terrace there are small hot springs, the shallow pools being commonly 18 inches or less in diameter. In many of these there is a continual slow stream of steam (or some other gas) bubbles entering from the bottom of the pool, but the supply of gas appears to be too scanty to raise the temperature of the spring water to the boiling point, as the observed temperatures in the springs range from 58° C. to 94° C. The overflow from these springs is scanty and only a few of them have built low sinter rims around their basins.

A different type of hot spring is found at the base of the terrace on the valley floor. These are intermittent springs, which might be classed as geysers, for at one stage of their intermittent activity, an eruption to a height of a few inches occurs. The largest of these springs is about 7 feet in diameter and has a funnel-shaped pool, the central part of which appears to be open for a depth of more than 10 feet. A sinter rim a few inches high encircles the pool, except for a narrow breach, which is perhaps artificial, on the north side. In this spring, a regular sequence of events is repeated at 20-minute intervals. At what may be considered to be the beginning of the cycle, the surface of the pool is about a foot below the outlet and at a temperature of 90° C. The level of the water then starts to rise and bubbles of gas 6 inches or more in diameter rise from the opening at the bottom of the funnel and come to the surface (Plate 8). Coincident with the rise in level, the temperature increases and reaches 94° C. when the pool is overflowing (Plate 9). Gas bubbles appear much

Plate 9. Intermittent spring. High stage.

more rapidly at the high stage and commonly the culmination of the rise is marked by an eruption of gas bubbles and water to a height of about 6 inches (Plate 10). The overflow at this stage was estimated to amount to 5 gallons a minute. After the climax, the water level gradually falls, the amount of gas emitted decreases and the temperature drops until conditions return to those existing at the beginning of the cycle.

A similar spring is situated less than 50 feet southwest of the one described, but is smaller and has a lower temperature. It also has a 20-minute cycle, but its high stage appears to coincide with the low stage of the larger spring.

Plate 10. Intermittent spring. In eruption.

Mud pots.—Several small mud pots were found on the terrace a short distance west of the more easterly 3-foot geyser. Unfortunately no temperature measurement was made in them nor was a sample of the water collected. A specimen of the mud was collected, however, the water extract of which was acid towards litmus paper. Most of the material composing the mud is a fine-grained isotropic mineral whose index of refraction is slightly greater than 1.51, and which is probably halloysite. Numerous diatoms are mixed with the clay. K. E. Lohman of the Geological Survey kindly provided the following report upon the small sample furnished him:

This material contains approximately 10 per cent of diatoms of the following species:

Achnanthes exigua Grunow	Rare
Denticula cf. D. crassula Naegeli	Frequent
D. elegans Kützing	Common
D. elegans var. kittoniana Grunow	Common
D. thermalis Kützing	Common
Epithemia gibberula var. producta Grunow	Common
E. turgida (Ehrenberg) Kützing	Rare
Navicula cf. N. halophila (Grunow) Cleve	Frequent
Nitzschia cf. N. amphibia Grunow	Rare
Pinnularia divergentissima (Grunow) Cleve	Common

Chemical composition of the water.—The three following analyses of waters from the geysers and hot springs of the region were made available by Dr. E. T. Allen of the Geophysical Laboratory:

	1 Parts per million	2 Parts per million	3 Parts per million
NH_4	4?	...	...
Na	239	216	282
K	33		
Ca	2	trace	trace
Mg	none	none	none
Fe	trace	trace	trace
Al	none		
CO_3	173	84	trace
HCO_3	129	244	512
SO_4	97	84	91
S_2O_3	1	...	...
S	none	...	...
Cl	47	30	70
F	11	...	...
B_2O_3	23	...	...
AsO_4	none	...	...
SiO_2	449	413	418
Total solids	1,208	1,081	1,307
Alkalinity	...	200	419.8
Hardness	...	trace	trace

1. Water from small geyser south of westerly 3-foot geyser. Analyst, E. T. Allen, Geophysical Laboratory. Collected by Nolan and Anderson.
2. Water from hot spring. Analyzed by S. C. Dinsmore, University of Nevada. Collected by R. F. Garnett, Beowawe.
3. Water from geyser. Analyzed by S. C. Dinsmore, University of Nevada. Collected by R. F. Garnett, Beowawe.

The waters appear to be most nearly related to the alkaline waters of the Yellowstone National Park as described by Allen.[5] He found that there the alkaline waters are characteristic of geyser and hot spring areas in which there is an abundant supply of ground water, and that acid waters were found only in regions in which available ground water was scanty. The presence at Beowawe of a few mud pots whose waters are probably acid may be the result of a local deficiency in the supply of ground water. A local deficiency of that character would result, if the steam or gas channels that feed these mud pots are surrounded by relatively impervious crushed or altered rock, thus preventing the ingress of ground water in the amounts necessary to produce alkaline waters.

Origin of the thermal activity.—The occurrence of geysers at Beowawe along a narrow belt at the contact between valley fill and hard rock is most unusual, as geysers in other localities are found in topographic or hydrographic basins. The writers believe that the unique situation at Beowawe may be the result of the coincidence of a relatively abundant supply of ground water with a considerable supply of heat close to the surface, which is easily transferred along a recent fault.

Because of the localization of the geysers, fumaroles, and hot springs along the linear contact between valley fill and the hard rock of the ridge, together with the tilting observed in the old sinter above the terrace, it seems probable that the thermal activity is controlled in large part by the recent fault, along which movement continued after the initiation of sinter deposition. The common occurrence of hot springs in a similar structural setting elsewhere in Nevada suggests that many of the recent normal faults provide channels along which considerable quantities of heat circulate; but the presence of fumaroles and geysers, rather than hot springs at Beowawe requires that the supply of heat be much greater than at the other localities, because the ground water supply here is probably at least as great as it is in the vicinity of most of the hot springs. This condition in turn may mean that the source of the heat is unusually close to the surface. The most probable inference regarding the source of the heat would seem to be a body of recently introduced magma, although no surface evidence of recent vulcanism was noted.

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[5] Allen, E. T., Hot Springs of Yellowstone Park: 16th International Geological Congress Guidebook 24, pp. 14-17, 1932.

At other places where geysers are found, the vents are commonly in basins in which considerable quantities of ground water are available. The apparent dominance of clear alkaline waters in the Beowawe hot springs and geysers suggests indirectly that here, too, is an ample supply of ground water, since Allen has shown that acid waters are formed when the ground water supply is limited.[6] We have no data as to the amount of ground water in Whirlwind Valley itself, but from the character of vegetation and the presence of springs, it is clear that, in considerable parts of it at least, the ground water table is at a relatively shallow depth.

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[6] Op. cit., pp. 14-16.

U. S Geological Survey,
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California Institute of Technology,
Pasadena, Calif.

SCIENTIFIC INTELLIGENCE.

CHEMISTRY AND PHYSICS.

The Therapeutic Agents of the Quinoline Group, Cinchophen, Plasmoquine, Nupercaine, Quinine, and Acridine Dyes, the Relation between their Chemical Constitution and Pharmacologic Action; by W. F. VON OETTINGEN, M.D., PH.D. New York, 1933. Pp. 301; 10 charts. American Chemical Society Monograph Series (Chemical Catalog Co.; $6.00).—While indispensable to pharmacologists and research chemists in the field of medicinals, this masterly compilation has value for physicians and all others concerned with new developments in this line. Better appreciation of the chemical relationships between remedies leads toward better therapeutics.

Beginning with the mother substance, quinoline, there are systematically recorded the facts of the chemistry and pharmacology of this substance, and of all those multitudinous derivatives which are known to act upon living things. Eleven large families of chemical substances are thus described. In nearly every case the interest centers about one or two important drugs such as the antimalarial quinine; the gout and rheumatic fever remedy, cinchophen; the heart-steadying quinidine; the local anesthetic, nupercaine; and the highly efficient, though tawny, germ-killer, acriflavine.

The exposition is clear, but no words are wasted. The traditions of the Chemical Monograph Series for appearance and accuracy seem to be fully upheld. If this book is but the first of a series covering the field of chemical pharmacology, and if the standard of completeness and authenticity set by von Oettingen is maintained, the literature of pharmacology will be decidedly enriched, and the tasks of many workers made easier. H. G. B.

America Self-contained; by SAMUEL CROWTHER. Pp. 340, New York, 1933 (Doubleday, Doran & Co.).—Pasted to the fly-leaf of this book is a letter to the reader, printed on Chemical Foundation stationery, which affirms that "The American chemical industry was founded by President Woodrow Wilson" and that "this book gives you a glimpse of how well the industry has lived its trust." Pages 69-108 of the book tell the story of the German domination of American chemistry, of the rescue of American chemistry by A. Mitchell Palmer, and of the progress of American chemistry under the guidance of Francis P. Garvan. The major argument of the author runs thus: "Science has changed the relations of nations . . . The United States has through the labor of her scientists become wholly self-sufficient . . . By chemical means we freed ourselves from every foreign clutch . . . Our chemists have written the charter of our freedom." HENSHAW WARD.

De la Turbine a l'Atome; by RENÉ BIED-CHARRETON, with preface by C. FABRY. Pp. vi, 198. Paris, 1933 (Gauthier-Villars et Cie., 25 francs).—This book discusses in simple and popular form many problems of physics from the point of view of an engineer. Opening with a consideration of the various sources of power available to man, the author is quickly led to the problems of atomic physics and the kinetic theory of gases. From this point it is only a step to the phenomena of radio-activity and the anatomy of the atom, and to the problem of radiation.

The author's physics is sound and his style agreeable. The book should be useful to those who are looking for an elementary survey of atomic physics. L. P.

GEOLOGY AND MINERALOGY.

Ueber Werden und Zerfall von Kontinentalschollen; by AXEL BORN. Forts. Geol. u. Pal. 10, Heft 32. Pp. 343-422, 10 maps, 1933.—This very valuable survey and synthesis of the greater geological structures of the continents can not be adequately reviewed here, and it is to be hoped that some one of our structural geologists will give us a translation of it. The memoir seeks to learn, through the ascertained structural facts, the essential laws that govern the geologic evolution of the continents—their historical growth, and in the main the changes that the geosynclines and mediterraneans have undergone. The terminology adopted is freed as far as possible from theoretical assumptions. The author is not presenting another book on regional geology, but is seeking to trace throughout all the continents the three greater, well-ascertained orogenic cycles, namely, Caledonian, Variscan, and Alpine. Each one of these orogenic groupings consists of several local phases, and such are now being so rapidly discerned that eventually more than the three cycles may be determined. In Asia, for example, the Alpine cycle appears to embrace two, one of Mesozoic and another of Cenozoic time. The three cycles are traced throughout the continental platforms of Europe, Africa, Asia, Australia, North and South America, and the various structural areas are presented graphically on ten maps.

The reviewer wishes that the author had classified the various types of subsiding areas into more than two kinds, namely, intra- and inter-continental geosynclines. Surely there is more than one kind of geosyncline within the continental platforms of Asia, Europe, and North America, and between continents lie the mediterraneans, while off the eastern side of Asia is another type of geosyncline. Oceans also are sinking areas, but they are historically, qualitatively, and structurally different from geosynclines. Born writes, further, of homogeneous (Appalachian) and heterogeneous geosynclines, and thinks of the latter as being wholly inter-continental. This is true of some, like Tethys, but the Cordilleran mesogeosyncline of North America is truly intracontinental, and yet it is composed of heterogeneous masses of differing ages.

All in all, Doctor Born has produced a striking synthesis, and one that will stimulate others, until we get to know the meaning of the greater structural features of the face of the earth. C. S.

Correlation of Dinantian and Namurian in Western Europe and *Early and Mid-Carboniferous Earth Movements in Great Britain*; by R. G. S. HUDSON and J. SELWYN TURNER. Proc. Leeds Philos. Soc., 2, Part X. Pp. 467-482, 455-466, 1933.—The first paper, which presents a general survey of the older Carboniferous, namely, the Tournasian, Visean, and Namurian epochs, of the Westphalian, Rheno-Hercynian, Saxo-Thuringian, and Moldanubian areas, has great value for American stratigraphers. The detailed correlation chart brings out this much broken record in a striking way; the breaks are due to the Variscan orogeny and the gaps are of long duration. At least fifteen faunal zones are recognized and the guide cephalopods, brachiopods, and corals are listed for each zone.

The object of the study is to present the earlier Variscan orogeny in the British Isles, as seen in the unconformities and the transgressions. This crustal movement "commenced in late Devonian times, reached its climax in the Carboniferous, and died away at the beginning of the Trias" (p. 455). In other words, the orogeny is now recognized as having an early or Lower Carboniferous (Bretonian) time of folding, in three phases; a Middle Carboniferous stage embracing the Sudetic, Erzgebirgian, and Asturian foldings; and a Permian or late Variscan stage including the Saalian and two phases of the Pfalzian folding. It should be noted that the Upper Carboniferous was a time of land, and of continental deposits. The authors conclude that "not only can Carboniferous movements in the British Isles be correlated from area to area, but also they can be linked with the Variscan orogeny in the geosyncline and are the expression of the orogenic phases in the Variscan foreland" (p. 465). C. S.

Permian Fossil Insects from the Arkhangelsk District, Part I, The Order Mecoptera; Part II, Neuroptera, Megaloptera and Coleoptera, with the Description of Two New Beetles from Tikhie Gory. Acad. Sci., U. R. S. S., Trav. Inst. Paléozool., 2. Pp. 23-62, pl. 4, text figs. 1-34; pp. 63-96, text figs. 1-19, 1933. *On the Permian Family Archescytinidae (Homoptera) and its Relationships*, Bull. Acad. Sci., U. R. S. S. Pp. 883-894, 1933; by A. MARTYNOV.—In recent years more than 600 specimens of fossil insects have been collected from the Upper Permian (Kazanian) of the Archangel district, in the valleys of the Sojana and Kama rivers. The first paper cited above describes 25 species (22 new) in 10 genera (3 new). These Russian forms are closely related to the Lower Permian faunas of Kansas, and both regions probably had similar climatic (semiarid) conditions. Of the Neuroptera there are 6 new species in 3 new genera, and of the Megaloptera, 2 new forms and a new genus. Of greatest interest are the Coleoptera, represented by 5 new forms in as many new genera. The third paper treats of 5 new species of Homoptera in 3 genera, 2 of which are new. C. S.

Geologic Map of the Appalachian Valley of Virginia with Explanatory Text; by CHARLES BUTTS. Pp. viii, 56. Richmond, 1933 (Virginia Geological Survey, Bulletin 42).—This relatively large-scale map (1:250,000) reflects the results of a lifetime study of the stratigraphy of the Appalachian Valley, though the field work upon which the map is immediately based was carried out during the field seasons of 1926-1932. The map and the 18 structure-sections accompanying it constitute an important contribution to the understanding of this complex and critical part of the Appalachians. They should be of great use in the class room, especially in structural geology and stratigraphy.

The map represents the area from the northwest foot of the Blue Ridge Mountains in Virginia to the West Virginia, Kentucky, and Tennessee State lines. The Pre-Cambrian rocks are mapped together with a single pattern. All of the Paleozoic systems from the Cambrian to the Pennsylvanian, inclusive, are found in the area; the Ozarkian and Canadian are ranked as systems coördinate with the major divisions of the Paleozoic. The very brief description of each of the formations in the notes accompanying the map is not to be regretted, in view of the fact that a complete illustrated report upon these formations of the Appalachian Valley in Virginia is already in course of preparation.

The Quaternary alluvium at the foot of the Blue Ridge is indicated by a light over-pattern that does not obscure the patterns of the underlying formations. There are very few igneous rocks in the area and, although their distribution is shown accurately, no attempt is made to classify them either petrographically or with respect to their ages.

A complete tabulated summary of the stratigraphy accompanies the report. A composite columnar section is placed near the margin of the large map sheet for convenient reference.

EARL INGERSON.

Serviço Geologicos, Lisbon, Portugal. 1919, 1928, 1932. The Geological Service of Portugal has recently published three quarto and two octavo volumes. The former give detailed statements of the special phenomena in Portugal of the great Lisbon earthquake of November 1, 1755. Volume II (1919, pp. 283-474, plates I-V) includes the districts of Santarem and Portalegre; III (1928, pp. 475-950, figures and plates) that of Lisbon; IV (1932, pp. 955-1014) is devoted to the districts north of Lisbon, viz. Leira, Castelo Branco, Coimbra, Guarda, Aveiro, and Vizeau.

The reader does not need to be reminded of the historical importance of the Lisbon earthquake of Nov. 1, 1755, both as to its severity and the extent of area affected. It is stated that in Lisbon ten to twenty thousand lives were lost and property to the value of £20,000,000 destroyed. These facts give special interest to the results of the careful study of this earthquake recorded in the present volumes. The author is Francisco Louis Pereira de Sousa (1870-1931).

The octavo volumes, XVII and XVIII, contain many interesting papers on a wide range of geological subjects, well illustrated with plates and maps. Volume XVII opens with an obituary notice and portrait of the distinguished geologist, to whom science owes the three quarto volumes here noticed.

The Hawke's Bay Earthquake of February 3, 1931. Bulletin 43 of the Department of Science and Industrial Research. Wellington, N. Z. Pp. 116 with figures and maps (price 2 s.).—New Zealand has long been known as frequently subject to earthquakes, but it is only now that the one of February 3, 1931, can be described as a serious disaster. The province of Hawke's Bay, on the east coast of the North Island, was severely shaken, especially near the towns of Napier and Hastings. A loss of life, estimated as about 260, is mentioned and damage much in excess of the £2,500,000 paid by the Government and Insurance Companies.

The Pyu Earthquakes of 3d and 4th December, 1930, and subsequent Burma Earthquakes up to January, 1932; by J. COGGIN BROWN and P. LEICESTER. Memoirs Geol. Surv. India, vol. 62, Pt. 1. Pp. iii, 140; 6 pls., 3 figs. Calcutta, 1933 (price 1 s.).—The town of Pegu in Burma, not far north of Rangoon, was practically destroyed by an earthquake on May 5, 1930, with great loss of life. This shock was felt over a land area of about 220,000 square miles. Other aftershocks followed and on December 3 and 4, shocks occurred which destroyed the town of Pyu, also with loss of life. Many other places in Burma felt shocks of greater or lesser intensity. This memoir describes all the phenomena in detail, with an interesting discussion, by J. Coggin Brown, of the geological conditions and their bearing on the causes of the earthquakes.

Preliminary Report on the Long Beach Earthquake; by HARRY O. WOOD. Bull. Seismolog. Soc. Amer., vol. 23, pp. 43-56, pls.

4-10, 1933.—The Long Beach earthquake of March 10, 1933, in Los Angeles Co., California, is notable because of the extensive damage done to life and property in more than a score of communities. It is estimated that 120 persons lost their lives and many hundreds were injured. This publication presents concisely the phenomena, scientifically considered, as well as the facts of interest to the public. The last are shown by excellent photographs. The area of the disturbance and intensity of the shock are regarded as not differing greatly from those of the Santa Barbara earthquake in 1925. The serious nature of the disaster is attributed "to poor construction on bad natural ground in a rather densely populated district."

Studies of Blasting recorded in Southern California; by H. O. Wood and C. F. Richter. No. 1. Bull. Seismolog. Soc. Amer., vol. 21, pp. 28-46, March, 1931. No. 2, Ibid., 23, pp. 95-110, July, 1933.—These studies are interesting because of the special phenomena described and the care with which these have been recorded; also because of their relation of those of minor earthquakes.

Report of the State Geologist on the Industries and Geology of Vermont, 1931-1932; George H. Perkins, State Geologist. Pp. viii, 387, 74 figs. Burlington, Vt., July, 1933.—This volume has a special interest since it is the eighteenth of the series brought out in a period of thirty-five years by Professor Perkins. He was made the State Geologist in 1898. The five chapters in this issue have the following titles: 1, The Marble Industry of Vermont, by G. H. Perkins; pp. 1-315, figs. 1-52. 2, Geology of Athens, Brookline, and Westminster; pp. 316-47, figs. 53-65. 3, Areal and structural geology of Putney; pp. 348-57, figs. 66-70; both 2 and 3 by C. H. Richardson. 4, The Last Lake of Stowe Valleys; pp. 358-62, fig. 71, by E. L. Bigelow. 5, Metamorphism near Rutland; pp. 363-82, figs. 72-74, by E. J. Foyles.

The first paper is an exhaustive discussion of the Vermont marble industry. This includes a detailed account of the various prominent localities, some of them dating back 150 years. The varying physical characters are also presented; also, the methods used in the quarries, and other points of interest.

Bulletins Géodésique; by G. Perrier, Secretary. (J. Hermann, Paris.)—This organ of the "Association of Geodesy" has recently issued the three numbers for 1933. These include: No. 37 (Jan. to March), No. 38 (April to June), No. 39 (July to September). No. 37 gives a statement of the work of the Commissions with their preliminary reports. Nos. 38 and 39 contain papers by various authors on new instruments and methods. For example, the following: Use of Laplace azimuths in the adjustment of triangulation by W. Bowie, Chief of the U. S. Coast and Geodetic Survey and President of the International Geodetic and Geophysical Union (No. 39, pp. 237-249). The Secretary, Gen. G. Perrier follows (pp. 250-278) with provisional reports: (1) as to the number of bases established (1930-31-32) in eight countries (57 in all: 39 for the United States); also, of the triangulations (pp. 261-278) established in thirteen countries from Canada to Siam.

Tilleyite.—A new mineral from the contact metamorphic zone at Crestmore, near Riverside, California. It is described by E. S. Larsen and G. C. Dunham, Amer. Mineralogist, vol. 18, p. 469, 1933.—The composition is $Ca_2SiO_4.CaCO_3$; crystallization probably monoclinic. It is white and fine granular in structure with one perfect cleavage, $\parallel$ 100. Associated species are: Merwinite, wollastonite, spurrite, vesuvianite, grossularite, etc. Named in honor of Professor C. E. Tilley of Cambridge University.

Occurrence and Physical Properties of North Carolina Marble; by JASPER L. STUCKEY and JAMES FONTAINE. Bulletin No. 5, Engineering Experiment Station, University of North Carolina, Raleigh, May, 1933. Pp. 24 (20 cents).—Marble is not common in North Carolina, being limited to 6 or 8 counties in the western part of the State. Of the various localities, the only one, in which commercial marble has been quarried, begins at Hewitts, Swain County, extends southwest on the Valley River to Murphy and along the Nottely River into Georgia. In texture, the medium-grained variety predominates, though, at times, it is also coarse and, to a limited extent, fine-grained. The prevailing color is blue, sometimes dark blue, less often white or mottled; occasionally rose tinted or flesh-colored. Some of these varieties take a good polish, and, being dolomitic, have both strength and resistance to the weather. It is consequently an excellent building stone, as shown, for example, in the Cherokee County Courthouse of 1926-27.

The Determination of the Feldspars in Thin Section; by KARL CHUDOBA, translated by W. Q. KENNEDY. Pp. 74; 50 figs. London, 1933 (Thomas Murby and Company, cloth 6/6; paper 4/6).—This is an excellent translation of a small handbook published in German ("Die Feldspate und ihre praktische Bestimmung," 1932). It gives concise and practical help in the important and often difficult problems involved in the determination of the feldspars in thin section. The book contains fifty well-drawn and helpful figures. It is of interest to note that the translator recognizes that the customary English spelling of feldspar (felspar) is incorrect and due to a wrong derivation of the word. This was pointed out by Dana in the first edition of The System of Mineralogy published in 1837. W. E. F.

Elements of a National Mineral Policy. Published by The Mineral Inquiry, 29 West 39th Street. Pp. 162. New York, 1933 (price $1.25).—This small book, which was prepared under the supervision of an editorial committee consisting of C. K. Leith, Chairman, H. Foster Bain and S. M. Marshall, is the outcome of a conference on "Minerals in Their Political and International Relations" held in New York in 1933. This conference was organized by "The Mineral Inquiry," which is a group of economic geologists, economists, engineers, etc., which is studying minerals in their public relations and is affiliated with the American Institute of Mining and Metallurgical Engineers. The book includes some nineteen short papers by different members of the conference, together with a "General Statement" by the chairman in which he sums up the various aspects of the subject.

W. E. FORD.

The Peninsula of Yucatan: Medical, Biological, Meteorological and Sociological Studies; by GEORGE CHEEVER SHATTUCK and collaborators. Washington, 1933. Carnegie Institution of Washington, Publication No. 431. Pp. xvii, 576; 69 pls., 30 figs. Quarto.—This is essentially a report of three medical expeditions to Yucatan (1929-31) organized by the Harvard Department of Tropical Medicine under the Carnegie Institution of Washington.—The following statement is made: "It was expected that the medical studies would add materially to published knowledge of disease in Yucatan, and it was hoped that new light might eventually be shed upon the collapse of the Mayan civilization by linking this medical knowledge with historical evidence relating to disease in the Peninsula" (p. xv).

An opening section presents in compact form the historical, cultural, and physical background for medical and other studies. There follow details of the medical surveys of specific localities. Beside descriptions of housing, sanitation, incidence of disease, blood studies, and basal metabolism, material coming more directly within the sphere of readers of this Journal, is that from bacterial and serological investigations, and that on helminthic and protozoan parasites. The contributions to natural history of the peninsula by J. C. Bequaert and W. J. Clench will probably prove of even greater interest. These include notes on botany, non-marine mollusks, arachnida, and insects, with lists of reptiles, and their protozoan and helminthic parasites.

The volume is copiously illustrated with photographs, charts, and maps. A question may be raised whether the inclusion of subjects so widely different under a single cover is wise; also whether a "coöperative" enterprise of the kind reported here is not somewhat fictitious.

LESLIE SPIER.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Recent Advances in Plant Physiology; by E. C. BARTON-WRIGHT. Second Edition. Pp. vi-x, 341; 54 illustrations. Philadelphia, 1933 (P. Blakiston's Son & Co., $4.00).—The appearance of a second edition of this very worthwhile work, attempting to give a summation of the more recent trends in Plant Physiology, is an encouraging index of the approval given to the first edition. The present volume is particularly notable for its improved arrangement of the subject matter, rather than for the inclusion of new work since 1928. By this more logical arrangement and greater subdivision of the material discussed the work approaches the status of a good current textbook of Plant Physiology.

The subjects treated are: Absorption of Water and Transpiration, Carbon Assimilation, Nitrogen Metabolism, The Raw Materials of Plant Nutrition, Translocation, Respiration and Growth. These features are treated in nine chapters while the first edition covered the same subjects together with considerable material on soils and humus in six chapters. The treatment of soils and humus has been eliminated. The clarity and continuity of the book has been improved by this new arrangement and greater subdivision of the subject matter. The discussion of the various topics is essentially the same as that of the earlier edition with relatively few new citations to the literature. It is a work of particular value to the advanced student of Plant Physiology desiring to become acquainted with many of the present trends of this science.

CARL G. DEUBER.

Rassenkunde und Rassengeschichte der Menschheit; VON EGON FREIHERR VON EICKSTEDT. Pp. 936; 3 pls., 613 figs., and 8 maps in color. Stuttgart, 1934 (Ferdinand Enke, RM. 72.50, bound RM. 76.50).—This work is monumental in more than one sense. It pictures the multiple facets of humanity and offers sources of information, to which anthropologists, biologists, ethnologists, geographers, historians, prehistorians, and sociologists can turn for helpful hints. No part of the earth where man is found is left untouched. The movements of races past and present and the pressure of racial forces are traced. Racial problems of the present are discussed at length. To the illuminating text, there are added an abundance of well-chosen illustrations from every part of the globe and a bibliography unmatched for its completeness.

GEORGE GRANT MAC CURDY.

Great Men of Science; by PHILIPP LENARD (translated from the second German edition by H. Stafford Hatfield). Pp. 389; 62 ill. New York, 1933 (The Macmillan Company, $3.00).—In this book a Nobel medalist in physics outlines the lives and the contributions to science of sixty-five distinguished men, covering a period from the earliest records of history to the close of the nineteenth century. Although the sections devoted to each man are kept separate, the author has preserved an excellent continuity of subject matter and the book traces in very clear fashion the evolution of scientific thought. At the same time the characters and personalities of the men stand out as individuals, and in relation to one another. The style of writing is simple and direct, with no attempt at literary embellishment. The translator brings the reader closer to the author by following quite literally the original German; at times this is perhaps carried a little too far. The impression gained on reading the book is that of a central theme worked out in a series of sketches whose sincerity and unity of purpose bespeak on the part of the author a reverence for his characters and a genuine devotion to his subject. A. T. WATERMAN.

PUBLICATIONS RECENTLY RECEIVED.

Recent Advances in Plant Physiology; by E. C. Barton-Wright. Second Edition. Philadelphia, 1933 (Blakiston's Son & Co., $4.00).

The Kinetics of Reactions in Solution; by E. A. Moelwyn-Hughes. Oxford, at the Clarendon Press. New York, 1933 (Oxford University Press, $5.00).

The Geology of the Country around Reigate and Dorking; by H. G. Dines and F. H. Edmunds. London, 1933 (H. M. Stationery Office, Price 4/–. Accompanying 1-inch colour-printed map, Price 2/–).

Handbuch der Bodenlehre; by E. Blanck. Vols. IV, VII, VIII, IX, X. Berlin, 1930, 1931 and 1932 (Julius Springer Verlagsbuchhandlung).

Charters and Basic Laws of Selected American Universities and Colleges. New York City, 522 Fifth Ave., 1934. The Carnegie Foundation for the Advancement of Teaching in Coöperation with Purdue University. Compiled and edited by Edward E. Elliott and M. M. Chambers.

Report of the Librarian of Congress for the Fiscal Year ending June 30, 1933. Washington, 1933 (Supt. of Documents, 75¢ cloth).

Handbook of Frogs and Toads; by Anna Allen Wright and Albert Hazen Wright. Vol. I. Handbooks of American Natural History, edited by Albert Hazen Wright. Ithaca, N. Y., 1933 (The Comstock Publishing Co., $2.50).

College Physical Science; by Paul McCorkle, and J. Arthur Lewis. Philadelphia, 1934 (P. Blakiston's Son & Co., $2.00).

Actualités Scientifiques et Industrielles. La Paléontologie & les Grands Problèmes de la Biologie Generale. Adaptations et Mutations. I. Berceaux et Migrations by Prof. C. Fraipont and Dr. Suzanne Leclerq. (Prix 9). II. Position du Problème by C. Fraipont (Prix 6). No. 67. Organisation et Principes de L'Enseignement en U. R. S. S. Les relations entre la Science et L'Industrie by J. J. Trillat (Prix 12). 76. L'Ancienne et Nouvelle Lagique by Rudolf Carnap (Prix 8). Paris, 1933 (Hermann & Cie).

Easily Interpolated Trigonometric Tables with Non-Interpolating Logs, Cologs and Antilogs; Frederick W. Johnson. (The Simplified Series Publ. Co., 1381 Third Ave., San Francisco, Cal.) 6A binding $1.85 and No. 7, $3.50.

DR. WILLIAM M. DAVIS

An Associate Editor of this Journal since 1900, and Professor of Geology at Harvard University 1899 to 1912, died on February 5 in his eighty-fourth year.

DR. JOHN JOLY, of the University of Dublin, died on December 7* at the age of seventy-six. Few men have had so brilliant a career. He devoted himself first to mineralogy, later to physics, and then to the application of radioactivity to geology. What he accomplished, especially in the last line of research, is fully presented in the obituary notice given in *Nature* of January 20, p. 90.

DR. DUKINFIELD HENRY SCOTT, the distinguished English paleobotanist, died on January 29 at the age of seventy-nine.

DR. THOMAS SWALE VINCENT, professor of physiology in the University of Manitoba in 1904, and later of the University of London, died on December 31 at the age of sixty-five.

DR. F. L. KITCHIN, paleontologist in the Geological Survey of Great Britain, died on January 20 at the age of sixty-three.

MR. ARTHUR EDWARD PEARSE WEIGALL, the British archeologist, especially devoted to the antiquities of Egypt, died on January 2 at the age of fifty-three.

DR. BENJAMIN A. BENSLEY, professor of zoology at the University of Toronto, died January 20, at the age of fifty-eight.

KNUD RASMUSSEN, the Danish geographer, known for his explorations of Greenland, died in last December at the age of fifty-four.

DR. WARREN UPHAM, of the U. S. Geological Survey from 1885 to 1895, later an archeologist, died on January 29 at the age of eighty-three.

DR. HOWARD CROSBY WARREN, professor of psychology at Princeton University, died on January 4 at the age of sixty-six.

DR. EDWARD WIGHT WASHBURN, chief chemist of the Bureau of Standards, died on February 6, at the age of fifty-two years.

DR. HOMER COLLAR SKEELS, botanist in the U. S. Department of Agriculture since 1907, died in January last.

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* Erroneously given as the 8th, in the January number, p. 79.

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The Editors of *The Observatory* possess for sale only 3 complete sets of the Magazine (Vols. 1 to 56). There are, however, several shorter sets for sale for the 23 years 1887 to 1909 (Vols. 10 to 32). Those of our readers who possess incomplete sets of the Magazine and wish to add thereto are invited to communicate with the Editors, Royal Observatory, Greenwich.

A specimen monthly number of Vol. 56 (1933) will be forwarded on application.

The Observatory, founded in 1877 by Sir WM. CHRISTIE, Astronomer Royal, has been edited in the past by W. H. M. CHRISTIE, E. W. MAUNDER, A. M. W. DOWNING, T. LEWIS, H. H. TURNER, A. A. COMMON, H. P. HOLLIS, S. CHAPMAN, A. S. EDDINGTON, H. SPENCER JONES, F. J. M. STRATTON, J. JACKSON, J. A. CARROLL, W. M. H. GREAVES and W. H. STEAVENSON.

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APRIL 1934

THE PLEISTOCENE CLIMATE OF BERMUDA.

KIRK BRYAN AND R. C. CADY.

ABSTRACT.

The climate of the present and that of the Pleistocene are similar in that both are characterized by polar ice and, therefore, are "glacial." As shown by C. E. P. Brooks, the dynamic complex of temperature and pressure gradients, of wind systems, and ocean currents is persistent in these two times and to be distinguished from the "non-glacial" conditions of the middle Paleozoic. Because of this similarity with the present it is possible to reconstruct the climate of the Pleistocene for any area and such a reconstruction is here attempted for the Island of Bermuda, whose successive layers of eolianite and soil have been recently interpreted by Sayles on a climatic basis. Basing the analysis on the assumptions that the sea level was lower, and that the continental ice masses gave rise to air temperatures and air pressures in summer and more or less throughout the year similar to those now existing in winter, the conclusions follow: (1) that the winds were stronger; (2) that, assisted by the outflow of melt water, the Gulf Stream was shifted eastward from the Atlantic seaboard and southward in the mid-Atlantic; (3) that the storm tracks converged on Cape Hatteras and followed the Gulf Stream on more southerly courses. These changes, together with concurrent phenomena, gave Bermuda a colder but not too severe climate, and increased the wind velocities to the extent that strong gales prevailed for fifteen to twenty-five per cent of the time. Such conditions were favorable to dune-building as postulated by Sayles. On the other hand, interglacial time was marked by less wind than at present and Sayles' conclusion that conditions for soil formation were favorable, is supported.

INTRODUCTION.

The great ice sheets that lay on the land areas of the northern hemisphere during the Pleistocene imply by their mere existence that the climatic conditions of the present could not have then prevailed. Consideration of the climatic differences between the present and the past may be divided into two phases: (1) the time and duration of abnormal epochs, and (2) the analysis and definition of the climatic elements for the world as a whole, or for a certain area at specific times in the past. The chronological phase of the problem has been vigorously attacked by many able geologists during the past century. There has, however, been little agreement on the characteristics of the climate for any time in the past or for any one place during geological history. The difficulties inherent in attaining correct solutions to the numerous problems presented in paleoclimatology are very great. Thus it may be agreed that, at the same instant in the Wisconsin epoch, an ice mass 1,000 to 2,000 feet thick covered both Chicago and Boston, but it does not follow that these places had the same local climate, although both must have had a climate much unlike that of the present. Outside of the glaciated regions the physical evidences of past climate are much more difficult to interpret, and, granting a correct interpretation of the evidence, it is not easy to picture precisely the whole climatic regime. Nearly all attempts to speculate in paleoclimatology have been made by geologists whose investigations have led them to appreciate the interest and importance of the subject. These studies have generally been lacking in an adequate foundation on the principles of the physics of the air and on the results of progress in modern climatology. The authors present a study in this field with some trepidation and make no pretense to great learning in these subjects, but fortunately a leader has appeared in C. E. P. Brooks,[1] a meteorologist who has absorbed and set forth in a thorough-going fashion the geological evidence on climates of the past. Similarly, F. Kerner-Marilaun[2] has contributed a number of excellent ideas, useful in attaining a true concept of the types of climates that once prevailed.

As Brooks has shown in a masterly analysis, the present type of climate is essentially "glacial" or to use the continental terminology, kryogenic. Permanent ice yet exists at high latitudes, and the circulation of the atmosphere and oceans differs from that characteristic of a period of ice advance, such as the Wisconsin, more in degree than in kind. Throughout most of the Mesozoic and Paleozoic, however, there was no polar ice and the climate was distinctly "non-glacial," or akryogenic. A true picture of these ancient times, is therefore, difficult to reproduce with precision. The whole meteorologic complex was dependent on a dynamic relation different from that of to-day. The essential similarity, however, between the present and the Pleistocene makes possible a reconstruction of the climatic characteristics of an area during the Pleistocene. No great or violent readjustment of the existing atmospheric circulation is required. All that is necessary is to analyze the changes in the existing dynamic complex that the former existence of the great ice sheets logically induce. Whatever the origin of the sheets, their presence affected the general circulation of the air, the movements of ocean currents, the position of areas of high and low pressure, and the movement of storms. If these changes are followed step by step, it becomes possible to reconstruct the climate that must have existed at any locality.

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[1] Brooks, C. E. P., Climate through the ages: New York, 1926. Evolution of climate: Benn Bros., 1922.

[2] Kerner-Marilaun, F., Paleoklimatologie, VII + 512 pp., 21 figs., Berlin, 1930.

In the essay that follows such a reconstruction of the Pleistocene climate of Bermuda has been attempted. The speculation has been inspired by the work of Mr. Robert W. Sayles[3] on the geology of Bermuda. Nearly all the rocks now exposed on the island consist of eolianite, a consolidated dune sand composed mainly of fragments of marine shells and foraminifera. The eolianite is divided into successive formations, each of which rests on the eroded top of the next lower formation, from which it is separated by a soil zone. Sayles rightly interprets this relation to indicate that there were successive periods of dune formation separated from each other by periods of weathering and erosion when no dunes formed. The present is one of the periods of weathering and practically no new dunes are now forming. The ancient dunes rise above the now submerged platform of Bermuda, and a sea-level lower than that of the present seems necessary for their growth. As is well established, low sea-level is associated with glacial conditions, and soils and weathering with interglacial conditions. Sayles points out that the lowered sea-level of glacial time would expose broad flat areas suitable for furnishing calcite sand, and assumes that the climate would be more windy. The existence of corals during one of the periods of soil formation indicates that the surrounding sea was warmer than that of the present. Thus the time of soil formation seems to have been truly interglacial and this fact confirms the general correlation. The position of the Bermuda Islands in the southeastern part of the submerged platform implies that the dune-forming winds came mainly from the south or southwest. Also the cross-bedding of the eolianite in the main dips northeastward and implies southwest winds.

The present study was undertaken to test the plausibility of

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[3] Sayles, R. W., Bermuda During the Ice Age. Amer. Acad. Arts and Sci., Proc. 66, No. 11, pp. 279-468, 1931.

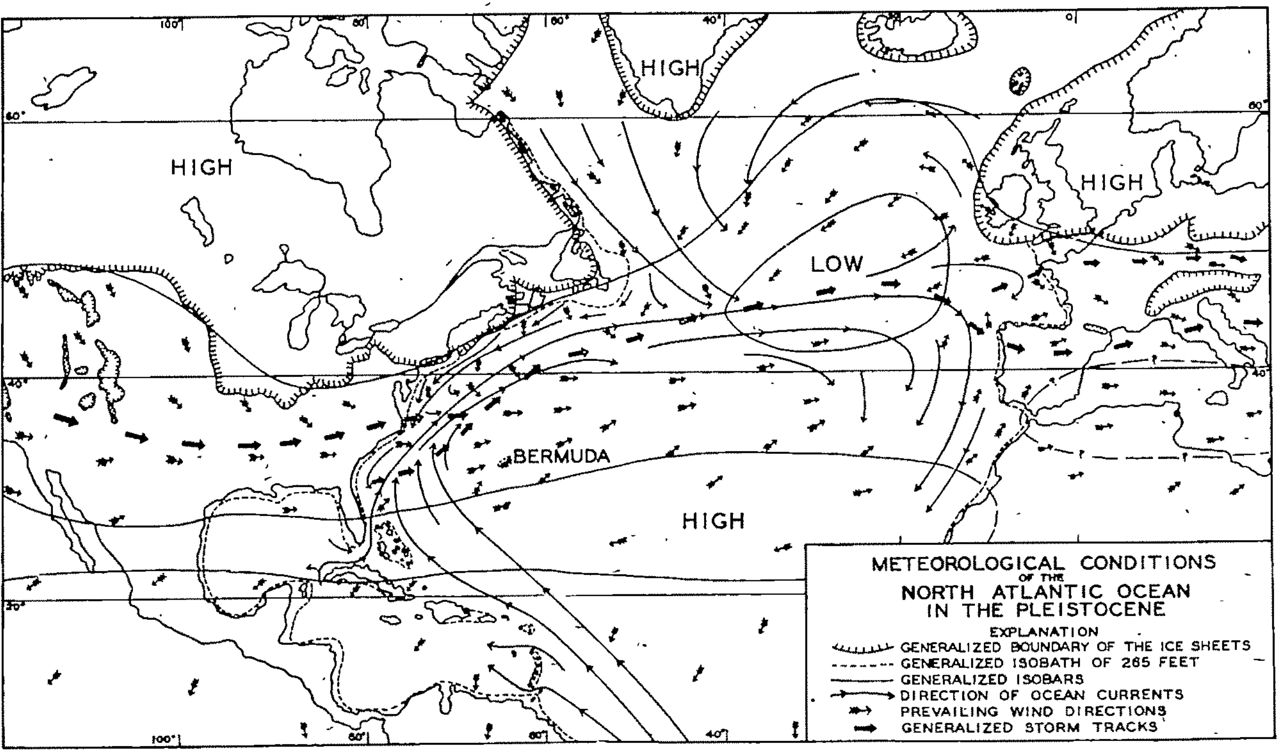
HIGH
HIGH
HIGH
LOW
BERMUDA
HIGH
100°
80°
60°
40°
0
60°
40°
20°
METEOROLOGICAL CONDITIONS OF THE NORTH ATLANTIC OCEAN IN THE PLEISTOCENE
EXPLANATION
GENERALIZED BOUNDARY OF THE ICE SHEETS
GENERALIZED ISOBATH OF 265 FEET
GENERALIZED ISOBARS
DIRECTION OF OCEAN CURRENTS
PREVAILING WIND DIRECTIONS
GENERALIZED STORM TRACKS

Fig. 1. Physical Conditions of the North Atlantic Ocean during Periods of Ice Advance.

the correlation adopted by Sayles by means of an analysis of the meteorology of the North Atlantic ocean and of Bermuda in particular during the periods of ice advance. Mr. Sayles was kind enough to allow the use of his manuscript before publication. The late Professor R. DeC. Ward, Professor C. F. Brooks, and Mr. Stephen B. Jones have given helpful advice and criticism. The work of C. E. P. Brooks may be considered the basis of the meteorological speculation, and the reader will note that the general assumptions here used relative to the circulation and dynamics of the air and ocean currents in the area of the North Atlantic ocean during the periods of ice advance resemble the general reconstruction outlined by him. The more special analysis of conditions on Bermuda directly follows from the general assumptions.

The Effects of the Depressed Sea-Level and the Borders of the Ice Masses.

The oceans are dynamic agents in the climatic sense, as well as in the geologic. Because of their mobility, they are capable of transferring vast masses of water from one locality to another under the stimulus of differential pressure induced by the non-uniform distribution of density of the sea water. Because of the huge masses of water actively involved in oceanic circulation, and because of the high specific heat of water itself, the oceans are capable of transporting such large quantities of heat that they may be said to transport climates far from their characteristic latitudes. The hackneyed example of the climatic differences between Labrador and the British Isles is in point. Keeping in mind, therefore, the fact that the temperature of the ocean water in any given locality determines to a large degree the temperature of the air, and that the temperature of the air in general controls its atmospheric pressure, and, through the pressure, the winds, it is clear that any force or factor which changes the circulation of the ocean waters may bring about drastic modifications in the climate, that may be either local or widespread.

During the maximum ice advance of the Wisconsin glacial epoch great quantities of water were locked up on the continents as ice. Sea-level was lowered eustatically about 265 feet.[4] If the widely held view that some of the earlier glacial epochs were characterized by still greater ice sheets is correct, then the lowering of sea-level at these times must have been correspondingly greater. However, these depressions of the sea-level made little change in the outline of the continents, except in a few localities. One of these localities was the Newfoundland Banks, where a lowering of the sea by 265 feet moved the shoreline some 300 miles east of its present site. As thus enlarged, the Banks jutted boldly into the Atlantic Ocean as a peninsula and assisted by grounded icebergs served to deflect the along-shore currents to the eastward away from North America. A more important modification of continental outline was the accentuation of the ridge which connects Greenland, Iceland, the Faroe Islands, and the British Isles. Although probably no part of the ridge was ever actually dry land it was sufficiently close to sea level so that, assisted by grounded icebergs, it became an effective barrier to circulating waters. Also the British Isles were, partly at least, fused to the mainland, and circulation south of the Isles was impeded. Thus interchange of water between the North Atlantic ocean and the Arctic ocean was almost impossible.

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[4] Daly, R. A., Swinging sea-level of the Ice Age. Geol. Soc. Am., **40**, pp. 721-734, 1929.

Another important factor which served to modify the distribution of warm and cold water in the Atlantic ocean was the direct debouchement of glacial ice into the sea. This phenomenon almost certainly occurred in the Gulf of Maine, probably on the Newfoundland Banks, in the Hudson Bay region, and adjacent to Greenland, Iceland, Scandinavia, and the British Isles. Also, with the prevailing colder temperatures the North Atlantic was prone to freezing, and the floe ice, thus formed, floated south with the icebergs derived from the glaciers and contributed to a wide-spread refrigeration of the surface waters. This circumstance is especially important, since during cooling the cooled water tends to sink unless ice forms. If the cooled water sinks, it cannot thereafter affect directly the temperature of the air. However, the fresh melt water, derived directly from the continental ice sheets and from the melting of the bergs and floe ice formed a layer over the heavier but warmer salt water, and must have been highly effective in cooling the air above as well as the sea water beneath.

The Gulf Stream.

The waters of the Gulf Stream, as it is to-day, enter the North Atlantic ocean by two main routes: through the Florida Straits from the Gulf of Mexico, and east of the West Indies as the Antillean Current. The two currents join off the coast of Georgia and proceed northeast along the coast of the United States. To a large extent the Gulf Stream owes its present volume to the fact that the strength of the Southeast Trade winds is greater than that of the Northeast Trades. The two Trade winds meet north of the equator in the Doldrums at all times of the year. In the South Atlantic ocean the Southeast Trades push a stream of water northward along the west coast of Africa, where the current turns northwest, crosses the ocean, and impinges upon the protruding horn of Brazil. There it divides unequally, the smaller part returning south along the South American coast, and the larger part entering the North Atlantic ocean as described above.

During the glacial advances of the Pleistocene, the Trade winds were unequally affected by the changed conditions. The large continental ice sheets of the northern hemisphere steepened the temperature gradient between the north pole and the equator, whereas the smaller bodies of ice in the southern hemisphere must have had little effect on the gradient from the south pole. Therefore, the Northeast Trade winds which are dependent on this gradient were strengthened. They were nearly as strong as, if not stronger than, the Southeast Trades. Doubtless the meeting place of the Trade winds (the Doldrums) was shifted southward. Consequently relatively more water from the equatorial current went south of the Brazilian salient, and, therefore, the quantity of warm water in the Antillean Current was diminished.

The depressed sea-level slightly constricted the Florida Straits, but as the current now passing through does not use the whole width of the Straits it may be that the constriction had no effect on the Gulf Stream. The temperature of the Gulf of Mexico was perhaps lower and the current passing out may also have had a generally lower temperature.

The factors named above indicate that the amount of warm water in the Gulf Stream was decreased or at least the absolute quantity of tropical heat transported poleward was decreased. It may be argued, however, that under the impetus of the quickened northeast Trade, and also because of the greater difference in temperature between the North Atlantic and South Atlantic waters the "North Equatorial" current would make a heavier contribution to the Antillean current. However, this water probably was cooler than that which came across the equator from the South Atlantic.

While moving from Florida to Newfoundland the Gulf Stream was more cooled than now. This cooling was accomplished in part by floating ice from Long Island, New England, and the Gulf of Maine; in part by cold melt water that spread over the warmer sea water and constantly mixed with it; perhaps in greater part by cold salt water brought up from the depths by powerful off-shore winds accompanied by a shift of the Gulf Stream to the east and in a smaller but considerable part by the cold winds themselves. Thus it seems likely that the Gulf Stream during the periods of glaciation possessed a lower temperature by reason of: (1) the partial substitution of the cooler water of the North Equatorial Current for the warmer water, which at present crosses the equator from the South Atlantic to feed the Antillean Current, and (2) the actual cooling of the Gulf Stream as it progressed up the coast of North America.

The foregoing discussion bears upon the general problem in several ways. An indeterminable proportion of the water of the Gulf Stream Drift was deflected north along the coast of northern Europe (the rest went south) where the cooling processes described for the coast of North America continued to operate; and similarly, the current was pushed westward away from the North American coast and out into the ocean by the action of fresh water, floating ice, and off-shore winds from the glacial ice sheets on the continent. Before the warm current could have travelled very far into the northern part of the Atlantic ocean, it must have been more cooled than it is now and, for this and other reasons very little, if any, warm water found its way into the Arctic ocean. Thus the strong temperature excess which to-day is centered over the northeast corner of the Atlantic was shifted to the southwest, and oriented in a more east-west position, axial to the 50° parallel or thereabouts. The effects of the changes outlined above upon the temperature of the air, the atmospheric pressure, the winds, and the storm tracks will occupy the remainder of this section of the paper.

The Regime of Air Temperature.

In the month of January the isotherm of 40° (Fahrenheit) crosses the United States slightly north of the 40th parallel of latitude. It enters the Atlantic near Chesapeake Bay, follows the east coast of the United States past New England, then strikes northeast to about 50° Lat. and 0° Long. From this point it bends sharply south, passing through the long axis of the British Isles, enters France and runs lengthwise of the Alps. This position of the isotherm roughly corresponds to the southern edge of those portions of the continents which are more or less covered with snow during the normal winter. The poleward loop of the isotherm over the northeast part of the Atlantic is due to the heating effect of the Gulf Stream Drift. In summer, the isotherm of 40° coincides quite closely with the 70th parallel of latitude. North of Scandinavia, however, it lies northward because of the influence of the same warm current. In Greenland also it bends southward along the margin of the southern half of the ice cap. In the southern hemisphere ice-bound Antarctica is bordered during the summer by a monthly mean temperature of approximately 30°F. It is important to note, then, that in summer as well as winter the margins of permanent ice caps and areas with more or less discontinuous mantles of snow have monthly mean temperatures of 30° to 40°F.

A rough sort of parallelism suggests itself between the air temperatures of the North Atlantic ocean and bordering continents under present winter conditions, and the ice-covered continents during the summers of the glacial epochs. True, in the glacial summer the sun would be higher on the horizon than in the winters of to-day. Other things being equal, this would make the glacial summers warmer than present winters. However the higher sun of the glacial summer probably was no more effective in warming the air at the edges of the ice than certain conditions which coöperate to keep our winter temperatures up, and which did not operate during glacial times. These conditions are: (1) the thinness of the present snow mantle, which permits frequent exposure of bare ground, even in our coldest months; (2) the lack of an area of high pressure powerful enough to exclude absolutely the importation of warm air by cyclonic storms (Siberia excepted); and (3) the higher absolute temperature of the oceans, which furnish much heat to the lands during on-shore winds. The analogy suggested is far from perfect, and should not be applied too literally, but it serves to indicate, in a very general way, an approximation to the temperatures that should be expected over the North Atlantic ocean and adjoining continents when the latter were covered with permanent ice caps. It will afford a skeleton model upon which to reconstruct the rest of the meterological elements of the glacial epoch.

From the above considerations, it is assumed in this study that the summer isotherm of 40°F. in glacial times coincided roughly with the present winter isotherm of 40°, except in the northeastern part of the Atlantic, where the Gulf Stream Drift now exerts its influence. This relationship is implied in Fig. 1 where generalized temperature-pressure lines and other meteorological elements are indicated. The air temperature at the edge of the glaciers would average, then, between 30° and 40°F. for the summer months. The mean air temperature in winter and the mean for the year are not very significant in this study. The present temperature gradient in summer along the 40° meridian from the equator to the southern tip of Greenland is about 0.6°F. per degree of latitude; in winter it is about 1°F. per degree of latitude. Since there is no evidence that the tropics were drastically cooled during the glacial epochs, the summer gradient at that time must have been only slightly less than 1°F. per degree of latitude, but may have risen as high as 1.5°F. in winter.

The extremely interesting and boldly conceived hypothesis proposed by Simpson[5] holds that glaciation was brought on by general rise in air temperature by reason of increased solar radiation and that the tropics were warmer than now during the whole of Pleistocene time. If this hypothesis is accepted the foregoing temperature gradients are too small. The resulting pressure gradients and winds would be greater also.

The Regime of Air Pressures and Prevailing Winds.

The changes in the pressure-wind system of the North Atlantic induced by the advent of ice sheets may be likened to the changes which are now observed to occur between summer and winter. The land masses of the higher latitudes, because they cool more than the oceans, acquire high barometric pressure, and conversely, the oceans acquire low pressure. All of the pressure areas, and therefore the winds become more pronounced. The pressure belts and consequent winds are shifted southward and of special note is the southward shift of the Sub-tropical High Pressure area.

However, three important deviations from strict analogy must be pointed out: (1) the mean position of the Doldrums may not have been much shifted southward in glacial times, whereas in the present winter it moves south with the sun; (2) the anticyclones developed over the north European and the North American ice sheets probably were more powerful than the modern winter anticyclones in the same regions; (3) if, as is believed, the Gulf Stream was shifted south of its present course during the glacial periods, the "Iceland" Low must also have been shifted southward. It lay, perhaps, as far as the 45° or 50° parallel of latitude and, doubtless, widened eastward. In the winters, the feeble warming of the sea by the poleward portion of the Gulf Stream was most pronounced and, therefore, the low pressure area may have migrated a few degrees northward in a direction contrary to its present winter migration. The southerly position of the "Iceland" Low both in winter and summer prevented its having any such weakening effect on the circumpolar whirl as it has to-day.

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[5] Simpson, G. C., Past Climates. British Science Guild, Pedler Lecture, 34 pp., 1929. Also Manchester Lit. Phil. Soc. Mem., 64, 1929-30.

The intensification of the pressure areas of the North Atlantic ocean, referred to above, was accomplished in part by stimulation of the planetary winds. The strengthening of the Sub-tropical High, and its southward shift probably more than counteracted any possible weakening of the equatorial belt of low pressure that could have been caused by cooling in the low latitudes. Consequently the Northeast Trades were more vigorous and the effect of this increase on the strength of the Gulf Stream was important. The westerlies were probably strengthened by the increase of the Sub-tropical Belt of High Pressure, and perhaps by the shortening of the distance between this "high" and the "Iceland" Low through the southward shift of the latter. The Polar Easterlies may not have been much stronger than at present, because any increase in the pressure difference between the polar high pressure area and the "Iceland" Low was offset by the increased distance that separated them.

Because the glaciers on the continents changed their shape only slightly from season to season, the general wind system probably preserved the pattern outlined above throughout the year. The "Iceland" Low may have shifted its position somewhat from summer to winter, but as the ocean water was always warmer than the ice-covered lands in the higher latitudes, it persisted throughout the entire year. In the winter, when the contrast between the temperature of the land and water was greatest, the Polar Easterlies, the winds from the ice sheets and the Westerlies were stronger. The Sub-tropical

Belt of High Pressure and Northeast Trade Winds over the ocean were probably also strengthened. The lands south of the ice sheets may have been warmed by the summer sun sufficiently to develop lower pressures. Whether this resulted in an actual break-up of the Sub-tropical Belt of High Pressure over the lands at that season, or merely in its narrowing and weakening, depends on the relative potency of the circumpolar whirl. If a break-up took place the winds which blew off the ice sheets flowed without interruption to the equator and at the ice borders they should have had a northeasterly direction. However, "fossil" sand dunes in northern Germany and in Gascony were formed by west winds, and as sand would be free to blow only in the summer, these westerly winds must have been the summer winds. In order to account for westerly winds in summer it is necessary to suppose that the path of winds into Africa was barred by higher pressure over and south of the Mediterranean Sea. Thus the west wind in mid-Europe is explained by supposing that the Sub-tropical High Pressure Belt north of Africa persisted through the summer, and that winds blew from the south of Europe to meet the winds from the anti-cyclones over the British and Scandinavian ice sheets. Both these wind streams turned to the east, crossed Europe, and then flowed into a low that probably was centered near Arabia. These southerly winds from Africa constituted the weak counterparts of the westerlies, and consequently cyclonic storms were free to penetrate northern Africa to produce the heavier rainfall which is believed to have prevailed there during the glacial epochs.[6] Probably also, the Sub-tropical Belt of High Pressure persisted perennially in North America because the mass of land in the proper latitudes is narrower than in Africa, and, therefore, less effective in lowering the pressure by raising the air temperature.

Cyclonic Storms.

During the glacial epochs, two great controls coöperated to shift the main tracks of extratropical cyclonic storms farther south: (1) pressure, and (2) temperature with accompanying moisture. The effect of pressure on extratropical cyclones may be stated as a law: lows are attracted by permanent areas of low pressure, and conversely, they are repelled by areas of high pressure. Because of the anticyclonic conditions existing over the continental ice sheets cyclonic storms were largely excluded from these areas. The cold and dry condition of the air over the ice sheets also tended to keep the cyclones south of the ice margins. Therefore the storm tracks, instead of converging in the vicinity of New England as they do to-day, entered the North Atlantic farther to the south, perhaps in the vicinity of Cape Hatteras.

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[6] Brooks, C. E. P., Le climat du Sahara et d'Arabie. La Sahara (edited by Masaji Hachisuka) Soc. d'editions geogr. maritimes et coloniales, Paris, 81 pp., 1932.

The region immediately west of Cape Hatteras and northward to the edge of the ice sheet appears to have had a strongly continental climate characterized by low winter temperatures followed by rapid rises in temperature. Such meteorological conditions are favorable to the production of river ice, and ice jams appear to have occurred with great frequency as suggested by Wentworth.[7] He has shown that the Potomac and many other southern rivers produced scratched and striated boulders which were deposited in river terraces and also in the fan deposits that mantle the Sunderland and later Coastal plain terraces. Some of these boulders are so large as to suggest that they were rafted downstream in blocks of ice.

Over the ocean, then as now, the courses of the storm tracks were determined largely by the warm air and consequent low pressure induced by and located over the Gulf Stream. Near the coast of Europe, storms avoided the European ice sheets and the frozen Arctic ocean. The tracks, therefore, were bent south toward the Mediterranean region and did not enter the northeastern Atlantic as they do at present. Probably some of the storms went north of the Alps, particularly in the summer, but this path must have been less favorable than the one farther to the south. Kessler[8] has adduced proof that the climate was of abnormal severity and believes that central Germany was the locus of storms that went north of the Alps.

The general increase in intensity of the winds, already

[7] Wentworth, C. K., Striated boulders on the southern Coastal Plain of Virginia. Geol. Soc. Amer. Bull., 38, pp. 150-151, 1927.

Striated cobbles in southern States. Geol. Soc. Amer. Bull., 39, pp. 941-953, 1928.

Sand and gravel resources of the Coastal Plain of Virginia. Va. Geol. Survey Bull. 32, pp. 46-47, *et al.*, 1930.

Petty, J. J., Striated cobbles from Teays Valley, West Virginia. Science, n. s., 71, p. 463, 1930.

[8] Kessler, P., Das Eiszeitliche Klima und seine geologische Wirkungen im nicht vereisten Gebiet, 210 pp., 21 figs., Stuttgart, 1925.

referred to, probably implies that, especially in the winter, cyclones were more numerous, more powerful, and that they probably moved faster where they did not interfere by reason of congestion.

The conditions of the general wind system, the pressure areas, and the storm tracks are shown diagrammatically in Fig. 1. This figure is drawn as nearly as may be to show the summer regime. In winter the conditions were doubtless quite similar, but a narrowing of the Sub-tropical High Pressure Belt over the oceans, and a slight widening and strengthening of this belt over the lands would occur. Also the "Iceland" Low was doubtless shifted a few degrees north of the summer position that is indicated on the chart.

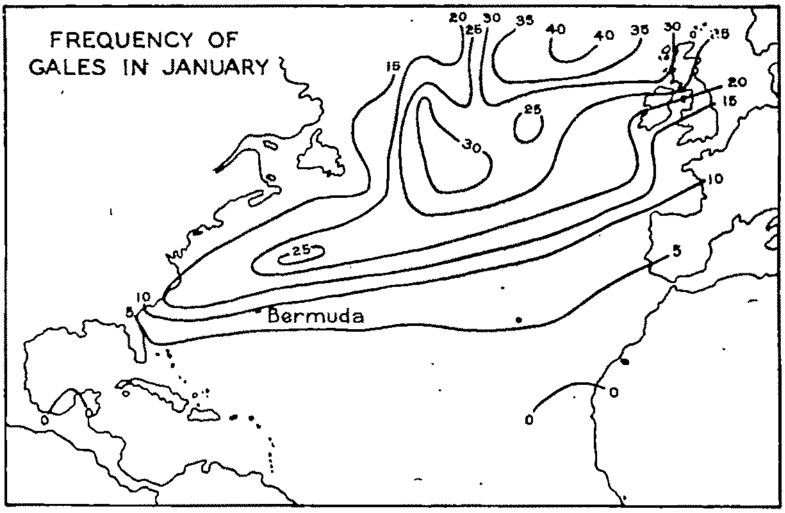

Fig. 2. Frequency of gales in January in per cent of time during which wind velocity exceeds 48 miles per hour; reduced to contours from U. S. Hydrographic Office Pilot Chart.

Bermuda During the Periods of Ice Advance
Present Climatic Conditions.

Bermuda lies at about 66° west longitude, and about 32° 30′ north latitude, and therefore some 600 miles east of the Gulf Stream. Because it is an island of small size, and its prevailing winds must cross a warm ocean current, its climate is mild and uniform. Whereas the mean temperature is about 70°F., the mean temperature of the warmest month (August) is slightly over 80°F., and that for January is 62°F. The precipitation is fairly regular, with a slight maximum in the winter. In January the average rainfall is 4.25 inches, and in June, 3.15 inches. The mean total for the year is 52.4 inches. Snow falls in the winter very rarely and it never lies on the ground for more than a few hours. The winter rainfall maximum is the result of the seasonal migration of the wind and pressure belts. In summer Bermuda is in the Sub-tropical Pressure Belt, but in winter, it is under the influence of the westerlies. Its climatic regime is therefore somewhat analogous to the Mediterranean type.

The winds as indicated on the U. S. Hydrographic Office Pilot Charts show more annual variation than the rainfall and temperature. In summer the wind blows 25 per cent of the time from the southwest at an average velocity between 20 and 25 miles per hour; 17 per cent of the time is calm. In contrast, the winter winds are chiefly from the northwest and southwest and blow with an average velocity of 25 to 30 miles per hour during 30 per cent of the time; only 8 per cent of the time is characterized by calm.

Not only in Bermuda but elsewhere in the Atlantic the force of the winds and the number of gales likewise increase from summer to winter. A gale is defined by the U. S. Hydrographic Office as a wind having a velocity of 48 miles per hour or more. In Fig. 2 these gales are shown numerically as the percentage of the time each month during which winds of such strength blow. It is important to note that the distribution of the gales coincides closely with the course of the Gulf Stream Drift, and with the mean track of cyclonic storms.

Most of the gales recorded in Fig. 2 are caused by cyclonic disturbances which are not only more pronounced in winter than in the summer but also more numerous. Over the South Atlantic and East Gulf Track, the storm frequency of January is 3.2 times that of July.[9] Tropical cyclones occasionally visit Bermuda in the period from July through October, but they are neither so violent nor so numerous as at localities farther south.

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[9] Bowie, E. H., and Weightman, R. H., Types of storms of the United States and their average movements. Monthly Weath. Rev. Suppl. No. 1, pp. 3-37, 1914.

Eastward Shift of the Gulf Stream During the Periods of Ice Advance.

At present the Gulf Stream flows about 600 miles to the west of Bermuda, but it has already been stated that the following factors operated during the glacial advance to shift it eastward and thus decrease the distance: (1) lowering of sea-level, (2) wedging effect of melt water from the glaciers, and (3) bodily displacement of the Gulf Stream by off-shore winds. The shift of the Gulf Stream eastward toward Bermuda may be roughly calculated. Sea-level was lowered by about 265 feet and taking the average slope of the continental shelf of the United States in the latitude of Bermuda as about 3.7 feet to the mile, the eastward displacement of the Gulf Stream would be about 70 miles. The cold counter current, fed by glaciers along the coast, to the north forced the Gulf Stream farther out into the ocean. This water although cold also tended to override the warmer because of its relative freshness. Exactly to what extent this force operated is not easy to estimate, but it probably was at least as effective as the first cause and thus may have produced a shift of 70 miles. Because of the steepened pressure gradients between land and sea the winds were at that time, as now, prevailingly off-shore, and blew more constantly and more powerfully than at present. They pushed the Gulf Stream away from the shore, farther out into the ocean. C. F. Brooks[10] recently pointed out the effects during the winter of 1930-31, of uncommonly strong off-shore winds on the Gulf Stream in the Florida Straits. It appears that the current was narrowed perceptibly by an eastward displacement of its western edge, whereas its eastern margin was not free to move because of the presence of islands on the east. Doubtless the whole current would have migrated were it not so confined. The strong winds of glacial times may have caused a shift of at least 10 miles.

All of these factors were capable, qualitatively, of bringing the main body of the Gulf Stream nearer to Bermuda, but the exact amount of the movement cannot be stated. According to the foregoing rough estimates, the shift may have been as much as 150 to 200 miles, with a rather wide margin of error on either side. But even if this shift were less, any tendency to shift the Gulf Stream closer to Bermuda would bring also a train of effects tending to increase the storminess of the Island.

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[10] Brooks, C. F., Verbal communications; see also Mon. Weath. Rev., 1931.

Air Temperatures at Bermuda During the Periods of Ice Advance.

Because of the lack of data, no satisfactory quantitative result may be expected from a consideration of the temperature conditions of Bermuda during the glacial epochs. Nor is it of particularly great significance in view of the fact that the average temperature of the present winter is well above freezing. Assuming that the present winter temperature is roughly indicative of the summer during the periods of ice advance, and that the annual range of temperature was approximately the same as now, a value of 60° for the warmest month would be of the right order of magnitude, and for the coldest, between 35° and 40°. These values are probably too low as such a low average winter temperature would imply that a vigorous cyclonic climate could produce temporarily much lower temperatures than the mean temperature of the entire month. Snow and ice would form. On the other hand, the prevailing winds, then as now, blew across a warm current so that the temperatures of Bermuda must have much more regular and milder than those of the areas on the mainland in the same latitude, and, therefore, higher than the figures given above.

Air Pressure and Prevailing Winds at Bermuda during the Periods of Ice Advance.

If, as is probable, the Sub-tropical Belt of High Pressure was displaced south of its present average position in glacial epochs, Bermuda was in the belt of Prevailing Westerlies throughout the year. Both the prevailing winds and the storm winds were of the types characteristic of the belt of Westerlies.

Now the pressure gradient in the vicinity of Bermuda as measured from a generalized isobaric chart has an average value of 0.10 inch to each degree of latitude in August, and 0.22 inch in February. Empirical observations made by Prof. R. deC. Ward indicate that wind velocities over land surfaces at these gradients should be respectively 16 and 30 miles per hour. These values correspond fairly closely to those of areas of similar pressure gradient in the North Atlantic Ocean for the appropriate months as shown on the windroses of the U. S. Hydrographic Office Pilot Charts. If the temperature gradient, and hence the pressure gradient, between the ice-covered land and the ocean was of the same order of magnitude in the glacial summer as it is during the present winter, the glacial summers were characterized by winds with an average velocity of 25 to 30 miles per hour. These winds prevailed for about 30 per cent of the time and moved from the continent seaward. In the winter the direction probably shifted somewhat to the northwest, and the average velocities increased. There could not have been any retardation of the winds in the winter in spite of the relative weakening of the Sub-tropical High Pressure Belt over the Atlantic because of the cooling effect of the ice-covered lands. On the other hand, the "Iceland" Low was actually strengthened.

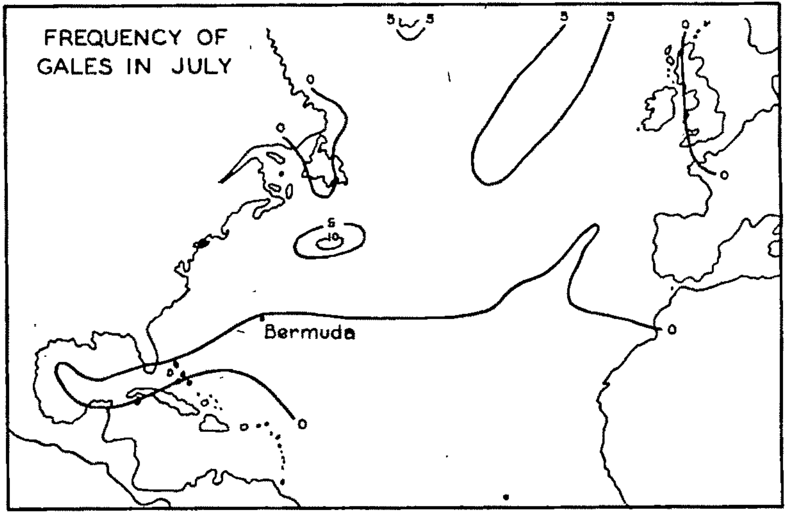

Fig. 3. Frequency of gales in July in per cent of time during which wind velocity exceeds 48 miles per hour; reduced to contours from U. S. Hydrographic Office Pilot Chart.

Considering that all available evidence indicates that ice advance produced a southerly shift of the climatic elements, an empiric estimate of wind velocities may be made. As recently shown by Chaney,[11] the vegetation zones, and presumably the climatic zones of the Pacific Coast, were displaced south about 5° of latitude during at least one of the glacial

[11] Chaney, R. W., and Mason, H. L., A Pleistocene flora from Santa Cruz Island, Calif. Carnegie Inst. Wash. Publ. No. 415, pp. 1-24, 1930.

epochs. In the area that lies 5° of latitude north of Bermuda the Pilot Charts for the month of February show northwest winds with a velocity of 37 miles per hour for 25 per cent of the time. (See also Fig. 2.) This area has more violent prevailing winds than Bermuda by about 10 miles per hour. If, then, the present wind belts are arbitrarily shifted south by 5° of latitude, the average wind velocities at Bermuda would be increased by 10 miles per hour. Thus for the summer months the wind velocity may have been nearer 40 miles per hour (for at least 25 per cent of the time) than the 30 miles indicated in the paragraph above. Figs. 2 and 3 are illuminating in this connection. In the present summer, Bermuda gets no winds of gale force; in the winter, such winds blow about 10 per cent of the time. If in an empiric experiment the lines of equal frequency of gales in winter be shifted south about 5° of latitude, Bermuda falls in an area characterized by winds of gale force for about 15 per cent of the time. Now the Gulf Stream was nearer Bermuda during the periods of ice advance, and the glacial summers were much like the present winters, and, therefore, this arbitrary southward shift may have some validity and may give a fair picture of the wind conditions in the glacial summer. The winds of the glacial winter were at least as strong and may have been more uniformly violent.

Cyclonic Storms at Bermuda During the Periods of Ice Advance.

At present the extratropical cyclones cross the United States on nine main tracks. Seven of them originate west of the Mississippi River and two of them lead from the Gulf of Mexico or from points off the southeastern coast of the Atlantic States. The first seven tracks enter the Atlantic between Chesapeake Bay and Newfoundland. When a glacial anticyclone more or less blocked their way from the mouth of the Ohio River to Long Island they must have been forced to enter the Atlantic near Cape Hatteras. Thence, avoiding the wide fringe of cold water along the coast, they probably had a course nearly due east for many miles. Upon reaching the Gulf Stream their course was altered to follow the northern edge of the warm water. The two storm paths that now skirt the Atlantic seaboard probably persisted, even under the changed conditions, and were merely shifted eastward a little, parallel with the shift of the Gulf Stream.

At present and in the average year, eight storms traverse the Atlantic Coast tracks, and 122 storms traverse the other seven tracks. The total number of storms in the glacial epochs was probably smaller even though the average rates at which the storms progressed was probably greater than now. As all the storm tracks converged near Cape Hatteras, some of these tracks lost their identity and there must have been too much crowding and congestion in the narrower strip that was open to them to permit the passage of more than, perhaps, 70 to 100 cyclones in a year.

Obviously, storm tracks are not rigid thoroughfares but represent average paths followed by storms. Some of the cyclones that left the coast went north of the normal path and were effective in the alimentation of the ice sheets. They had little effect on the winds of Bermuda. On the other hand as many storms would be expected to wander south of the tracks. If the normal tracks came within 400 to 600 miles of Bermuda, a certain percentage of storms must have approached nearer so as to be effective in yielding storm winds. The maximum wind velocities in a cyclonic storm lie in belts extending to 150 miles on either side of the moving center. If 5 or 10 per cent of all the storm centers, i.e., between 4 and 10 storms, came within 150 miles of Bermuda in the course of a year, they would contribute a very appreciable sum to the total wind velocity of Bermuda. In addition, if the number of storms moving on the tracks parallel to the eastern coast of the United States was increased during the glacial epochs, as is quite probable, the number of effective storms was thereby increased.

To conclude, then, if between 4 and 10 (or more) cyclones came close enough to Bermuda during the year to bring their maximum wind velocities, this circumstance and an average velocity of 30 to 40 miles per hour of the prevailing winds (blowing between 15 and 25 per cent of the time) would provide ample justification for assuming that at all seasons strong winds were characteristic of the climate.

Wind Direction during Periods of Ice Advance.

The distribution of the existing islands on the Bermuda Platform and the inclination of the inclined bedding of the eolianite, both have a bearing on the direction of the wind during the periods of ice advance and dune building. Sayles[12] points out that the islands have a northeast trend and lie on the southern part of the Platform. In the south and southwest parts of the islands, the cross-bedding dips northeast and indicates southwest winds. On the north shore of the main island there is a large dune built from the north, whereas, on the easternmost part of this island the cross-bedding dips southwest and indicates northeast winds. Sayles believes that the north and northwest winds were too strong to allow the preservation of dunes whereas the south and southwest winds built up the land progressively from northeast to southwest.

The analysis given in the foregoing sections of this report indicates that during the glacial periods cyclonic storms passed north of the islands but closer to them than at present. The wind movement into the successive lows of a general storm track north of the islands would give rise to southerly and southwesterly winds. However, when a high passed on this track the winds would be northerly. The storms which at present follow the coastwise track (Fig. 1) also give rise to northerly on Bermuda. During periods of ice advance, such storms existed, as already mentioned and each of them contributed to the number of northerly gales.

When first discovered, Bermuda was forested and it yet supports a good vegetative cover. The cold and stormy weather of glacial time would not have been so severe as to have prohibited the growth of forests and grass although the species may have been different. Hence it must be assumed that dune-building took place in the presence of vegetation. The calcite sand must have been picked up on the beach and moved inland to be held by the vegetation. Observations in all parts of the world show that under these conditions dunes are built on all shores and move inland. The stronger winds build the larger and higher dunes on the shores on which they impinge. These winds, however, do not displace the sand piled up in the opposite direction by minor winds on the farther shore of narrow islands and peninsulas.

If these principles are applied to Bermuda one would expect the higher dunes and therefore the larger islands on the northerly parts of the platform. However, during the waning of an ice sheet the sea-level would rise and drown the broad beaches so as to inhibit the formation of dunes before marked changes in meteorological conditions could occur.

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[12] Sayles, R. W., op. cit., p. 457.

During the rise of sea-level wave erosion of the dune sand and eolianite would occur. The greater the lag between rise of sea-level and change of the wind, the more likely it would be that the larger northern dunes would have been eroded by the presumably strong wave action on the northern coast.

Such a reconstruction of local conditions fits the facts on the cross-bedding in dunes as set forth by Sayles, but as he has suggested, further observations on this phenomenon are desirable.

Climatic Conditions in the Interglacial Periods.

All available evidence indicates that the climate during the well-developed interglacial periods was milder than at present. The glacial ice sheets certainly disappeared from North America and northern Europe, but probably in the polar regions ice has never been entirely absent since the beginning of the Pleistocene period. Assuming that some ice persisted through interglacial time in the polar regions, but to a less extent than now, the distribution of the meteorological elements was quite similar to that of to-day. All members of the planetary wind system were present, although less vigorous than now. The lack of large ice masses at the poles decreased the poleward temperature gradient and therefore weakened the circumpolar whirl.

The sluggish state of the planetary winds was not conducive to the formation of strong and numerous cyclones on the polar front. Those that did traverse the belt of westerlies were feeble, slow moving, and were probably confined to the higher latitudes. As the extra-tropical cyclones were weak, the rainfall of the interglacial epochs was lower than now, particularly in localities that now lie in the margins of the subtropical areas. Moreover, a relatively greater proportion of the rainfall was furnished by local convectional thunderstorms. The run-off from such downpours was greater than from gentle cyclonic rains, even of much greater quantity, so that in many regions the balance between erosive and depositional agencies was disturbed.

In general, so long as ice remained in the polar regions the climatic conditions resembled those of to-day as to the distribution of winds, of temperature, of pressure, and of storms. The intensity of the climatic elements varied in relation to the area of ice remaining in the high latitudes. Complete absence of ice at the poles would produce a "non-glacial" climate as described by C. E. P. Brooks in Chapter XI of *Climate Through the Ages.* Such a climate is the antithesis of the glacial and interglacial climates here described.

The effect of the change from glacial to interglacial conditions at Bermuda would be to reduce the number and intensity of storm winds. Indeed, in some of the warmer interglacial epochs it may be that cyclones of the extratropical type were unknown. The rainfall may have been reduced somewhat, although the decrease is not recorded in the soil zones or the fossils described by Sayles. The warmth and dryness of the maximum of the interglacial could not have been great enough to reduce the vegetative cover so as to induce movement in the dunes, whereas the decrease in the force of the winds was decidedly unfavorable to dune movement.

Conclusion.

In the foregoing essay, the several factors which must have entered into the Pleistocene climate of Bermuda have been separately analyzed. It has been necessary to reconstruct the dynamic complex of the interrelated ocean currents and wind systems of the North Atlantic for that time. This reconstruction is based on two primary assumptions: (1) that sea-level was lowered as water was abstracted to form the great ice caps, (2) that the existence of the ice caps gave, throughout the year, air temperatures and concurrent air pressures similar to those which now exist in winter when the same area is covered with snow. If these assumptions are correct, the conclusion follows that pressure gradients and winds were stronger. The Sub-tropical Belt of High Pressure appears to have been reduced and shifted southward. Taken in conjunction with cold water that, especially in summer, was discharged into the North Atlantic from the ice which fronted on the sea, these premises, and the conclusions derived therefrom, lead to the important conclusion that the Gulf Stream was shifted easterly away from the coast of North America and southerly in its course through the mid-Atlantic. From this important conclusion it follows that present Iceland Low and also the storm tracks were shifted in a southerly direction.

As for Bermuda, the southerly shift of the storm belt and the Sub-tropical Belt of High Pressure, gave it a climate with more severe temperatures, but the more important effect was to give it prevailing westerly winds of moderate intensity. Similarly, the shift of the storm belt made it subject to cyclonic winds that must frequently have attained the violence of strong gales.

By a more empiric line of argument much the same conclusion is reached. The area just north of Bermuda by 5° latitude has at present numerous winds of gale violence. These winds are related to the existing storm track parallel to the Gulf Stream. If this belt be shifted southward by 5° as the vegetative zones on the Pacific Coast seem to have been shifted, then Bermuda would have about the same degree of storminess postulated under the more elaborate analysis.

If the assumption is made that the present climate is transitional between the true glacial and the maximum of an interglacial period, then an analysis of Bermuda's climate at such a maximum can be made. In such a time the Arctic ice would be smaller, the snow cover in high latitudes less continuous and the consequent pressure gradients lower, cyclonic storms feebler, storm tracks farther north, and the Sub-tropical Belts of High Pressure expanded. Bermuda would have an accentuation of the conditions which now obtain in summer, and therefore, would be even more free of winds than at present.

Thus the detailed reconstruction of Bermuda's Pleistocene climate confirms the reasonableness of Sayles' interpretation of the geologic evidence. The glacial maxima were characterized by flat beaches and strong winds capable of piling up dune sand. Yet there was a temperate climate with greater precipitation than now to provide vegetation to hold the sand on the land area and fix it in heaps. During the minima or interglacial periods calms prevailed, but the precipitation was not so small that soil-forming processes were inhibited.

The general analysis may be applied to many other areas bordering on the Atlantic. So far as information goes, it fits the existing evidence on climatic conditions of the Pleistocene at various localities, but this evidence is so sparse, and so difficult to interpret correctly that a summation at the present time appears inadvisable. As study of this evidence continues, it may be that errors in the analysis will appear. On the other hand it is hoped that this particularization of climatic conditions during the Pleistocene will stimulate further detailed analysis and an intensive search for geologic evidence of the predicted and predictable climatic conditions of the Pleistocene.

CAMBRIDGE, MASSACHUSETTS.

THE AGE OF THE POCONO.*

DAVID WHITE.

In his recent paper on the "Great Catskill Delta," Dr. George H. Chadwick,[1] after proposing some correlative readjustments of the pre-Pennsylvanian late Paleozoic formations which carry marine faunas along the northern border of the Appalachian Trough, pays his respects to what I regard as the typical Mauch Chunk and Pocono, on the eastern side of the Trough, both of which he says are Devonian. The same views have since been briefly set forth by him in this Journal (November, p. 479). Praise is due the stratigraphic and paleontologic studies by Doctor Chadwick and his co-workers across northern Pennsylvania, southern New York, and northern New Jersey, which have yielded correlations and interpretations of much significance and value; but, however conclusive the stratigraphy and paleontology may be along the northern border of the basin, it would seem either that, in passing around the elbow or head of the Trough, he has failed to contact the true Pocono, or that the beds regarded by him, possibly correctly, as the type section of the Pocono are older than those known as Pocono along the east side of the late Paleozoic embayment.

Concerning the various terranes, some newly named, lying abreast of the northern margin of the Appalachian bituminous coal fields, I have had little to do and have little to say. My interest and the following discussion center on the pre-Pennsylvanian formations which carry fossil floras along the *east* side of the Trough, and especially in what are there known as the Pocono and Mauch Chunk, which for good reasons I regard as Mississippian.

To orient the situation, I quote two paragraphs from Chadwick (pp. 106, 107) as follows:

> "In any case, even if we include as Pocono all the beds right up to the base of the Pottsville on the east side of the Carbondale syncline (for there are only ten feet of 'reddish' shale in the supposed Mauch Chunk there, according to [I. C.] White), no part of it is Carbonic in age. The main mass, indeed, is not later than of upper Chemung deposition (19-22?) Wellsburg.

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* Published by permission of the Director of the U. S. Geological Survey.

[1] George H. Chadwick, The Pan-American Geologist, vol. LX, No. 2, September, 1933.

From at least Potter County eastward, in Pennsylvania, there is no Early Carbonic strata present in the outcrop, the Pottsville beds resting directly upon the beveled Devonic strata, of which the local 'Pocono,' or 'Vespertine,' is everywhere but a fifth (and final) facies, increasing in age to the east. Thus, the type Pocono (whatever be the type) is the oldest of them all. With the converse and fallacious upward shift of all facies and divisional names westward, the 'Vespertine,' or 'Pocono,' finally gets up into the marine Waverly shales in western Pennsylvania and Ohio, none of which is Pocono at all. Pocono is Devonic in age.

"One cannot omit some reference to the Mauch Chunk red shales that on the Lehigh River surmounts and extensively interfingers with what is there called 'Pocono.' There is not a smitch of evidence that this Mauch Chunk ('Umbral') red shale is of Early Carbonic age, nor any reason for supposing such a large wedge of post-Devonic beds to suddenly reappear in the section, beneath the transgressing Pottsville. Compare figure 4. Hence Mauch Chunk may have to follow Pocono into the category of these Devonic delta sediments."

If the type section of the Pocono, as it may eventually be located, agreed upon, and defined, is found from the evidence of the invertebrates to be Devonian, the name Pocono may be shifted to a lower register in the columnar section, but the fairly distinctive group of continental gray conglomerates, coals, and shales extending from East Mauch Chunk, on the slope of the Pocono Mountains, southward along the east side of the Appalachian Trough as far as Tennessee, and called Pocono since that name was proposed to supersede Rogers' Vespertine, will not thereby be proved Devonian.

The Pocono of which I write is a moderately distinct stratigraphic and sedimentary unit between the red Mauch Chunk and the red Catskill. On the Lehigh River below Mauch Chunk, where it is now well exposed, due to modern road building, it embraces about 1,250 feet of beds, as measured by Winslow, consisting mainly of gray sandstones, many of which are coarse sand or very fine gravel, coarse conglomerates, numerous coal beds, and shales with some greenish flaggy layers. The lower portion presents here and there relatively thin red shale deposits. The Pocono retains these general characters throughout the greater part of its outcrop along the eastern border of the Appalachian Carboniferous from East Mauch Chunk to Big Moccasin Gap, 2-3 miles east of Gate City, Scott County, Va., and about 2½ miles north of the

Tennessee line. Here it is the upper part of the Grainger of Hayes. It varies considerably in thickness, being 1,400 feet thick opposite Pottsville, Pa., 1,700 feet in Price Mountain, Montgomery County, Va., and about 700 feet thick at Big Moccasin Gap.

Though detailed stratigraphic mapping, modern in standard, covers but relatively small areas of the eastern Pocono, general descriptions of both the Pocono and the Mauch Chunk will be found in the reports of the Pennsylvania geological surveys and in folios covering portions of the outcrops published by the U. S. Geological Survey. Summarized descriptions of the formations in Pennsylvania will be found in the Summary Final Report of the Second Geological Survey of Pennsylvania, volume 3, part 1, a work apparently unfamiliar to most geologists, in which Lesley expresses some of his final conclusions.

Separated by the easily eroded Mauch Chunk from the resistant, generally conglomeratic Pottsville, the Pocono forms a continuous well-marked topographic feature throughout the eastern zone of the Appalachian embayment.

This Pocono represents a very interesting and as yet too little studied chapter in the orogenic history of the Appalachian Trough. Through a long distance, reaching as far as southern Virginia, a region east of the present eastern Catskill belt was uplifted by an orogenic movement which gave origin to a broad flanking coastal plain on which was spread an aggregate of conglomerates and coarse sands ranging from 600 to nearly 1,800 feet in thickness, and stretching for more than 500 miles to the southward, during a distinct period of erosion of the eastern crystallines. The eastern limits of this formation have been obliterated. Like the overlying Mauch Chunk and Pottsville the Pocono with its terrestrial contents is still thickening and becoming coarser as far east as outcrops remain, i.e., in the direction from which came the new supply of sediments. The original deposit was certainly broad, and the orogeny which produced it, though minor, was not insignificant. The remarkable persistence in character as well as in thickness of the formation in the N.-S. direction point to a corresponding extension of the uplift from the latitude of Mauch Chunk southward nearly, at least, to Tennessee.

On the broad coastal plain land deposits, represented in particular by numerous coals, were from time to time laid down, interbedded with the sandstones, conglomerates, and fresh-water shales. Coals varying in number are present in every eastern section, from the Schuylkill River southward. Some of them, overlying subaerial soils, are thick enough at many points to tempt the miner. A country mine was very recently under development near Dauphin, north of Harrisburg. Thin coals outcrop in the Broad-Top district of Pennsylvania. Mining was formerly carried on in the Sleepy Creek Basin east of Berkeley Springs, in northern West Virginia, and in several counties in Virginia, especially in Wythe County and in Pulaski County near New River, and commercial operations and shipments are now in active progress from Pocono mines in a large fenster, described by Campbell,[2] not far from Blacksburg, Montgomery County, Va.

The orogeny producing the Pocono also caused environmental changes other than mountain-building and the creation of a new coastal plain. To these changes, which presumably affected the climate to some extent, are due marked changes in the land plant life of the region. From end to end of its great belt the formation is characterized by a flora markedly in contrast with that found in the Catskill of northeastern Pennsylvania and farther to the south. Instead of *Archæopteris,* which is omnipresent and characteristic of the Catskill and supposed Chemung and which is, I believe, unknown in beds so low as the Portage, the Pocono is populated by a flora characterized by a group of species belonging to *Triphyllopteris.* No Archaeopterid has yet been found in it, so far as I am aware. With this somewhat highly varied *Triphyllopteris* group occur slender Sphenopterids characteristic of the lower Mississippian from the Arctic to southwestern Virginia. Its Lycopods represent the *Lepidodendron corrugatum-scobiniforme* type (not *L. gaspianum*) which is plainly of Devonian extraction but appears to be characteristic of the Mississippian and coextensive with the above-mentioned Sphenopterids.

Aneimites, common in the Mauch Chunk, seems to overlap on the Pocono. Its earlier species, ranging from the Horton in Nova Scotia southward to West Virginia, are, in general, more characteristic of the basal portion of the Mauch Chunk, the middle and upper portions of which witness the introduction of *Cardiopteris* and other typical upper Mississippian genera. On the other hand, *Triphyllopteris* is apparently unknown as yet at any point in beds hitherto regarded as Devonian in age. It is apparently ancestral to *Rachopteris*, which in turn probably gave rise to the early Eremopterids and Mariopterids. The marked contrast between the fern-like forms which abound in the Pocono and the Archaeopterid flora of the upper Catskill has long been recognized and, though it is far from impossible that a surviving *Archæopteris* may be found in the basal portion of the Pocono, I have not yet been able to find it in the numerous sections from which I have gathered plant collections.

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[2] Campbell, M. R., and Holden, R. J., The Valley coal field of Virginia: Virginia Geol. Survey Bull. No. 25, 1925.

The facts above cited are not in agreement with the statement by Doctor Chadwick (p. 106) that "land plants are less common [in the Pocono] though not known to differ from the Catskill forms." Let me add that the *relative* lushness of the Pocono flora and the deposition of coals, as well as the rarity of red shales in the greater portions of its sections, point to a climate in this region more humid than that of the preceding Catskill or the succeeding Mauch Chunk. The climatic changes are consistent with changes in the map pattern, or in the elevation of the land, or both.

Viewed from both the diastrophic and the paleobotanical standpoints the Pocono of the eastern belt is Mississippian. It presents the most notable and clearly marked evidences of uplift, mountain building, and degradation, with climatic changes, seen on the east side of the Appalachian Trough between the beginning of the Devonian and the post-Mississippian uplift. The eastward changes in thickness and coarseness of its sediments imply an unconformity in that direction in which Devonian beds may have been eroded, together with the quartz-bearing crystallines.

With the reduction of the uplifted eastern belt and the subsidence of the Pocono coastal plain Pocono sedimentation, representing the first stage in the Mississippian cycle, terminates, and we see the succeeding Mauch Chunk, mainly red shales and sandstones with marine limestones near its base, laid down apparently with regularity and relative evenness of sedimentation, but really with considerable disconformity. Changes in both the strand and the area of uplift were accompanied by changes in climate, as shown not only by changes in the plant life, which became meager and reduced, while coaly deposits were rare and thin even in apparently favorably exposed areas, but also according to Stose by salt deposition in the early Mauch Chunk, especially in southwestern Virginia, now the center of salt and gypsum industries.

Marine invertebrates seem to be rare in the main body of the eastern Pocono in Pennsylvania, as is to be expected in view of its generally terrestrial origin. However, marine fossils are not unknown in it. In the Terrace Mountain sections, in Bedford County, recently described by D. B. Reger,[3] marine shells, assigned by Dr. George H. Girty[4] to the lower Mississippian, are found in Reger's Riddlesburg shales, about one-third of the way from the bottom to the top of the formation, nearly 1,100 feet thick, which as correlated by him, includes the Berea at the bottom and ends with the Burgoon sandstone.

It should be noted also that, on the authority of Charles Butts, the Pocono of Broad Top and Terrace Mountain is directly underlain by 2,000 feet or more of so-called Catskill red beds, which in turn are underlain by 3,500 feet of Chemung. Furthermore, the Pocono here is directly overlain by 1,000 feet of red shale (Mauch Chunk). Broad Top Mountain is in the same trough as the Northern Anthracite field. The sequence in the Broad Top field is very much like that of the Lehigh Valley southeast of Mauch Chunk. The main difference is in the greater proportion of red beds and the absence of the Chemung fossils in the Lehigh section. Instead of the Pocono being Chemung, the Chemung is represented in the median part of the 7,000 feet of red beds, so-called Catskill of that section.

On the other hand, in southwestern Virginia the opportunities for temporary marine encroachment on the Pocono coastal plain seem to have been more frequent. Near Wytheville, Va., Charles Butts reports interfingering of the Pocono sandstone at several levels with shales carrying a *Syringothyris* Burlington fauna. On Stony Creek, northwest of Wytheville, Va., *Syringothyris* cf. *S. textus* is common as much as 400 feet below coal beds formerly mined and from the shale associated with which I have collected a good representation of the *Triphyllopteris* flora. *Productus* cf. *P. fernglensis* also occurs commonly below the coal and *Triphyllopteris* horizons. Neither *Syringothyris* nor *Productus* is known in the Devonian of the Appalachian region.

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[3] Reger, D. B., Pocono stratigraphy in the Broadtop basin of Pennsylvania: Bull. Geol. Soc. Amer., 38, pp. 397-410, 1927.

[4] Girty, G. H., Pocono fauna of the Broad Top coal field, Pa.: U. S. Geol. Survey Prof. Paper 150-E, p. 127, 1928.

In southern Virginia the Pocono conglomerates are less in evidence and the quartz sands are not so cleanly washed, but coals of insignificant thickness, resting on old soils and shales with the *Triphyllopteris* flora, are present southward as far, at least, as the Tennessee state line.

The Mauch Chunk, generally regarded as more or less fully referable to the Chester epoch, varies from a thickness of about 1,300 feet at East Mauch Chunk and a maximum of about 3,000 feet at points along its eastern border to little or nothing as one passes far enough northwestward. The fact that in western Jefferson County, at Patton (mentioned by Doctor Chadwick), the zone containing the large-pinnuled *Aneimites* with broadly divergent lobes occurs within a few feet of the Pennsylvanian indicates high probability that only basal Mauch Chunk as originally defined, or Burgoon, remains at that point. A stage, probably the same, is represented in Sullivan County, and a short distance above the main Pocono north of Tyrone, where, however, a considerable thickness of red Mauch Chunk overlie it. Beds including conglomerates, generally slightly greenish and carrying coaly streaks, and Mississippian plants (probably Pocono), outcrop at several points in the walls of the Allegheny River between Mahoning and Red Bank Creeks.

The formation is reported to be 150 feet thick above Pittston where the so-called Pocono of that area is set down at 350 feet. Certainly, beds of Mauch Chunk and Pocono age, if both are present in the Narrows above Pittston, cannot be very thick, since the Catskill *Archæopteris* flora, represented by abundant *Archæopteris minor*, is found but a few hundred feet below the Pottsville which here falls within the upper Pottsville, dating apparently later than the Sharon conglomerate of western Pennsylvania.

In western Pennsylvania the limestone near the base of the Mauch Chunk, as originally defined, was early known as the "silicious limestone," and, north of the Broad-Top Basin, an approximately corresponding limestone, again carrying a marine fauna of supposed lower Chester age, is known as the Trough Creek limestone. Other local limestone deposits at or near this low horizon are reported in Lycoming County, also.

In West Virginia the limestone series embodying the Greenbrier attains a thickness of over 1,800 feet. It probably represents the deep phase of the Mississippian cycle on the eastern side of the northern Appalachian Trough. As to whether the lowest faunas in this limestone series, which, in my judgment, closely succeeds the Pocono, are of Ste. Genevieve, Warsaw, or St. Louis age, I am not qualified to judge, but I am inclined to conclude that Doctor Chadwick must never have seen nor heard of them when he says, "There is not a smitch of evidence that this Mauch Chunk ('Umbral') red shale is of Early Carbonic age, nor any reason for supposing such a large wedge of post-Devonic beds to suddenly reappear in the section, beneath the transgressing Pottsville."

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POLYMORPHIC PHENOMENA AND CRYSTAL STRUCTURE.

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I. DEFINITION AND CLASSIFICATION OF POLYMORPHISM.

It is easy to define polymorphism as the property possessed by certain substances of exhibiting different crystal structures under different physical conditions. In practice, however, it is frequently difficult to agree as to when a certain crystal structure has changed into another structure, because the changes (as evidenced by changes in the optical properties, in the X-ray pattern, etc.) sometimes are so small that they should be regarded as due to modifying influences of the environment on the same structure rather than to the development of a new structure. When for instance a crystal is heated, certain changes in the structure are always encountered. This has frequently been referred to as "homogeneous deformation" and is of course different from polymorphism. Other minor changes in the crystal lattices not due to a homogeneous deformation have also been considered by several authors as something different from polymorphism.

It seems to me, however, that the following definition is the most expedient one:

Polymorphism includes every possible difference encountered in the crystalline lattice of a substance of constant chemical composition, excepting homogeneous deformations.

This definition corresponds essentially to the one introduced by Fedorov.[1]

The deeper nature of polymorphism was revealed by V. M. Goldschmidt and co-workers,[2] who demonstrated the close causal relationship between isomorphism, morphotropy, and polymorphism. Since then the study of polymorphism has become one of the most interesting chapters of crystallography and is of dominant importance in comparing and correlating crystal structures. The manifold aspects of polymorphism, however, still introduce difficulties which are further accentuated by the lack of a systematic terminology. Fixation of the terminology and classification of the diversified manifestations

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[1] E. von Fedorov, Allgemeine Krystallisationsgesetze und die darauf fussende eindeutige Aufstellung der Krystalle. Z. Krist., 38, 321, 1903.

[2] Geochem. Vert. Gesetze VII (Die Gesetze der Krystallchemie). Det Norske Vid.-Akad. Skr. Oslo, No. 2, p. 90 ff., 1926.

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18

of polymorphism should therefore be of great help to students of these phenomena.

It is self-evident that the immediate cause of any polymorphic transformation is some change taking place in the space-lattice of the crystal. In order to describe such changes adequately it becomes advantageous to adopt the following terminology. One can speak of *types* of crystal structure in contradistinction to *variants* of structure,[3] and in order to distinguish between the geometrical symmetry properties and the physical symmetry properties of a crystal it is proposed to use the word "syngony" as pertaining to the geometrical symmetry and reserve the word "symmetry" for the physical symmetry properties. This is in accordance with a suggestion of Soret[4] which has been adopted by Fedorov.

The polymorphic changes occurring in crystals can then be grouped into three classes. In order of decreasing magnitude of the changes one has:

I. A complete alteration of the space-lattice with the formation of a new type of structure. Since the type of structure is changed this case could be referred to as polytypy.

II. A distinct change in the syngony (i.e. geometrical symmetry) of the space-lattice although the atomic arrangement, density, or cleavage properties are so slightly affected that the type of structure is preserved and merely a new variant of structure is formed. Such differences in the syngony properties could be referred to as polysyngony.

III. A change of the physical properties without any change of the syngony of the lattice. A new variant of structure is thereby formed, but the type is of course preserved. Such properties of a crystal could be referred to as polytropy.[5]

It is also worth mentioning that it has been possible to distinguish between different types of polymorphism on the basis of the physical behavior of the inversions; this is indeed the only kind of classification so far used. It is of further interest, however, that a deeper significance can be attached to this classification, for in each case the behavior of the inversion is directly conditioned by the special way in which the atoms rearrange themselves in the crystal lattices.

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[3] For definition and usage of these words see V. M. Goldschmidt, T. F. W. Barth, and G. Lunde, Geochem. Verteilungsges., V (Isomorphie und Polymorphie der Sesquioxyde). Det Norske Vid.-Akad. Skr. Oslo, No. 7, pp. 38-39, 1925.

[4] Ch. Soret, Cristallographie Physique, p. 70. Genève-Paris, 1893.

[5] In accordance with the terminology previously outlined it would seem logical in this case to use the word "polysymmetry." As will be explained in the appendix, however, historical reasons are against such a usage of this word, and therefore the word "polytropy" from the Greek "τρόπος" (way, manner, guise) is recomended here.

The appendix contains further historical comments that are believed to justify the usage of the nomenclature here adopted.

Two main types of inversion have long been recognized.[6]

I. The first type, as exemplified by the case quartz-tridymite, has been given various names, as sluggish, strong, delayed, etc. Wyrouboff[6] called it "polymorphisme heteroaxe" or "paramorphisme." Whatever name is used, this type corresponds in the great majority of cases to polytypy.

II. The other main type of inversion as illustrated, e.g., by the case α-cristobalite-β-cristobalite, has been referred to as rapid, weak, etc. (Wyrouboff: "polymorphisme isoaxe"). In all known cases it corresponds to polysyngony.

III. More recently a third kind of polymorphic transformation, the gradual change, has become known, e.g., the gradual transition in sodium nitrate. The few known cases correspond to polytropy; polysyngony is, however, supposable.

From what has been stated above it is seen that a remarkable parallelism exists between the two methods of classification.

It is true that rare exceptions occur, and that a few intermediate cases have been encountered where doubt exists as to which class they should properly be referred to. Such exceptional cases do not invalidate the general usefulness of the proposed classification. As distinct from mathematics and theoretical physics natural phenomena cannot be treated with schematic accuracy; all schematic classifications are to be regarded as idealized cases that approximately correspond to the physical facts.

A rapid review of the proposed classification of polymorphic phenomena is afforded by the following table:

TABLE I. Polymorphic Phenomena.

I	II	III
Polytypy	*Polysyngony*	*Polytropy*
Sluggish or delayed inversions	Rapid inversions	Gradual changes
Change of one type of structure into another	Preservation of the type of structure with change into another variant of structure	

II. THE MECHANISM OF POLYMORPHIC CHANGES.

1. Polytypy corresponds to a change of the type of structure and hundreds of examples of this kind of polymorphic inversion could be mentioned. But one typical example, for instance that of quartz—tridymite, is probably sufficient.

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[6] See G. Wyrouboff, Recherches sur le polymorphisme et la pseudosymmetrie. Bull. soc. min. France, 13, 277, 1890.

Physically the inversion means a complete rearrangement of all the constituent atoms with a consequent breaking down of the space-lattice of the crystal that has become unstable (e.g., quartz) and the formation of an essentially different space-lattice of the other crystal (e.g., tridymite).

2. *Polysyngony* may be a well-known word to many crystallographers but not so to most physical chemists. The phenomenon which is here called polysyngony is, however, familiar to all of us.

Two (or more) heteromorphous[7] modifications with different syngony properties are said to be in a relation of polysyngony if their respective crystal structures can be regarded as variants of the same structure type. Thus α-quartz and β-quartz—although differing in syngony—are both variants of the quartz structure; α-cristobalite and β-cristobalite, which are of cubic and orthorhombic syngony respectively, are variants of the cristobalite type of structure.

This type of inversion does not correspond to a complete rearrangement of the constituent atoms; the atoms are somewhat displaced, the lattice being thereby deformed, but not destroyed; and the type of structure is thus preserved. The mechanism of the polysyngonic inversion in α-cristobalite—β-cristobalite has already been described.[8] and additional examples of this kind of inversion need not be given here.

3. *Polytropy* has not been clearly defined before, so it may be salutary to explain the phenomenon more thoroughly.

Polytropy also pertains to crystals representing variants of one and the same structure type, but in distinction from polysyngony the respective crystals must now also belong to the same crystallographic syngony (i.e. the geometrical symmetry properties of their respective space-lattices must be identical, or essentially similar).

The significance of this definition may best be brought out by a few examples:

The gradual transition observed in crystals of sodium nitrate with rising temperature is a case of polytropy. This transition has been studied very carefully by Kracek and others,[9] and the mechanism of the gradual transition has been satis-

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[7] For a definition of the word "heteromorphism" see Appendix.

[8] T. F. W. Barth, The cristobalite structures. This Journal, 24, p. 107 ff., 1932.

[9] F. C. Kracek, Gradual transition in sodium nitrate. I. J. Am. Chem. Soc. **53**, 2609, 1931; also F. C. Kracek, E. Posnjak, and S. B. Hendricks, Idem **53**, 3339, 1931.

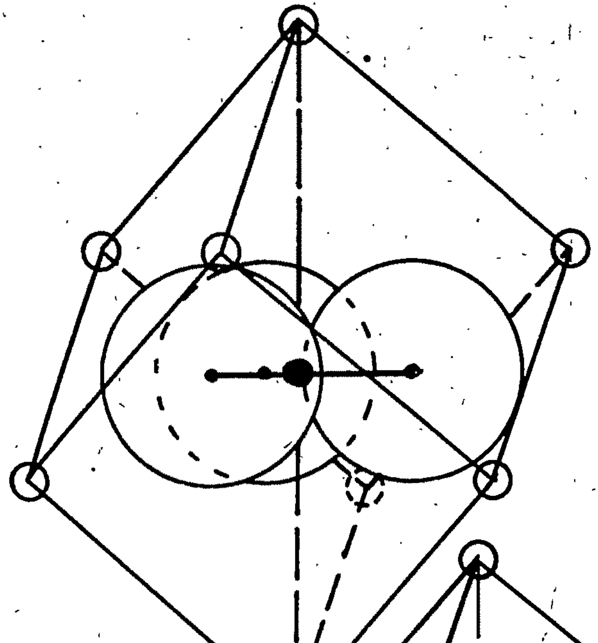

Fig. 1. A portion of the unit cell of sodium nitrate at 25° C. The nitrogen atom (black spot in the center of the rhombohedron) and the three oxygen atoms (large circles) are co-planar. The corners are occupied by sodium atoms.

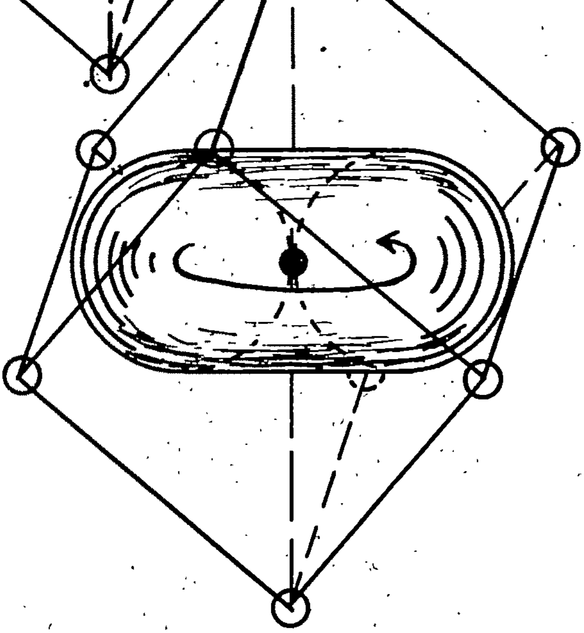

Fig. 2. The unit of sodium nitrate at 280° C. The nitrate-group rotates around the central nitrogen atom.

factorily explained. At ordinary temperature crystals of sodium nitrate are isomorphous with the space group 3Di of the trigonal syngony. The atomic arrangement corresponds to that of calcite. A part of the unit cell is reproduced in Fig. 1. The gradual transition observed corresponds to an initiation of a rotation of the nitrate group around the trigonal axis (see Fig. 2). The syngony of the crystal thereby remains trigonal, even the point group remains the same.

By virtue of the trigonal syngony the optical orientation of sodium nitrate also remains unchanged; but when polytropy is encountered in crystals of lower syngony this is usually not the case. A good example is here afforded by the behavior of potash feldspar (orthoclase), and since the true syngony of this mineral and the explanation of the peculiar relationship between orthoclase and microcline are problems that for generations have aroused the interest of mineralogists, a description of the polymorphic phenomena observed in this substance will be given special consideration.

III. THE POLYMORPHISM OF POTASH FELDSPAR.

The difference in behavior of different kinds of potash feldspar can now be rigorously classified according to the proposed scheme of polymorphism, a fact that might be construed as an indication of the felicitous character of the scheme. In this case the improved terminology seems also likely to clear the way for a more complete understanding of the crystal structure of all potash feldspars.

Some reliable physical data are available on potash feldspar; and the geometrical elements (crystallographic angles, etc.) have now been established more accurately by X-ray measurements than has been possible hitherto.

In Table II a compilation of these data is given.

As may be seen from the table, sanidine and adularia are both monoclinic yet different in their optical properties, especially in respect to the optical orientation. In contradistinction to orthoclase (including in this term both sanidine and adularia) microcline has a triclinic space-lattice, but nevertheless approaches adularia in its optical properties.

The conclusions from these facts expressed in purely descriptive terms without as yet trying to give any theoretical explanation of the observed phenomena will necessarily be that polysyngony exists between orthoclase and microcline, and that polytropy exists between sanidine and adularia.

TABLE II. Optical and Crystallographical Properties of Potash Feldspar.

	Refractive indices*			Extinction* on (001)	Optic angle*		Crystallographic angles**		
	α	β	γ				α	β	γ
Sanidine	1.517	1.521	1.521	0°	30°	‖010	90°00′	115°35′	90°00′
Adularia	1.518	1.522	1.523	0°	60°	⊥010	90°00′	116°03′	90°00′
Microcline	1.519	1.523	1.525	18°	80°	⊥010	90°01′	115°50′	89°55′

* The upper line represents "abnormal orthoclase" with the plane of optic axes in the symmetry plane.

The second line represents "normal orthoclase" with the optic axes normal to the symmetry plane.

These two kinds of orthoclase are here called sanidine and adularia respectively. The data represent extrapolated values for pure $KAlSi_3O_8$.

The optical data for microcline are also supposed to come close to those of $KAlSi_3O_8$, but no perfectly pure potash microcline has been measured.

(After H. E. Merwin. Refractivity of birefringent crystals. Int. Critical Tables VII, p. 28, 1930.)

** No pure potash feldspars have been X-rayed, so the angles above do not correspond exactly to those of pure $KAlSi_3O_8$. The variation in the angle β is consequently partly caused by an admixture of soda or lime. But the point of immediate interest to us is that so far all orthoclases (sanidines and adularias) have been shown to belong to the monoclinic syngony, whereas all microclines have been triclinic. (Cf. E. Schiebold: Neues Jahrb. f. Min., Abt. A, Beil.-Bd. 64 (Festband Brauns) 1931, p. 265.) This is also verified by several measurements by the present author.

Since, however, various explanations of the relation between orthoclase and microcline have already been suggested, it seems worth while to add a few words concerning the possible interpretation of these cases of polymorphism in potash feldspar.

A theory that has received much attention was first offered, many years ago, by Mallard, who regarded orthoclase as a submicroscopically twinned microcline (thus affording a case of apparent polymorphism). This theory accounts for so many details that it should be given serious consideration, but since X-ray measurements have shown that the crystallographic angles come closer to a monoclinic syngony in orthoclase than in microcline this theory seems to be doomed.

The only possibility left is, therefore, that the various polymorphic changes in potash feldspar correspond to distortions of the lattice or to a partial rearrangement of the constituent atoms. A suggestion of the possible mechanism of these changes is given in the sequel. This suggestion can now be offered only as a hypothesis, but it is of some general interest because it introduces an essentially new principle of polymorphic changes.

The structure of orthoclase has been studied by Schiebold[10] and by Taylor[11] with somewhat conflicting results. Both structures are based on a framework of distorted tetrahedra, but since Taylor's structure leads to very plausible interatomic distances (which is not the case with the structure of Schiebold) it is here accepted as the correct one. There are four molecules of $KAlSi_3O_8$ in the unit cell, which has been chosen so as to correspond to the usual crystallographic axes. From his crystal-structure determination Taylor concludes that "the real symmetry of sanidine cannot be monoclinic holo-

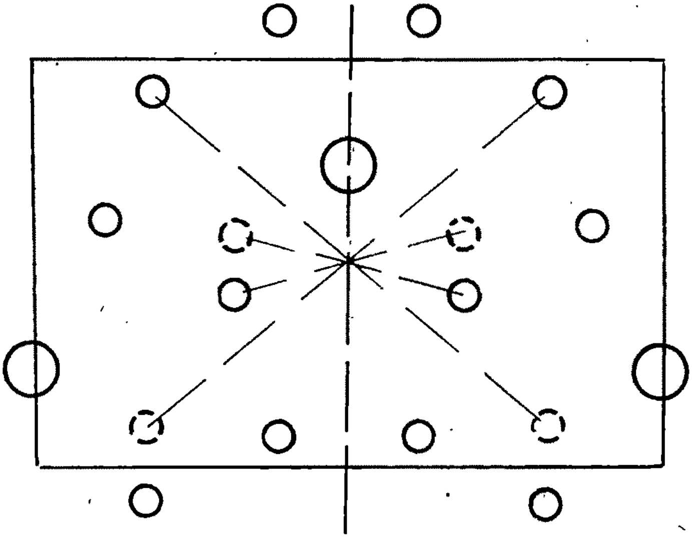

Fig. 3. Proposed structure of orthoclase (monoclinic) with Si + Al as variate atoms in all available positions. The picture shows a portion of the unit cell of the feldspar structure (after Taylor) projected on the face (001). Large circles represent K. Smaller circles represent both Si and Al. Oxygens are not shown; they surround Si and Al tetrahedrally. The cell has a symmetry center and each atom has therefore a corresponding atom of the same kind in a centro-symmetrical position; in order to avoid crowding the picture these positions are not drawn, but a few of them are indicated by broken circles; the heights of these atoms (above the plane of the paper) are much greater than the heights of the others. The monoclinic reflection plane is also easily recognized.

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[10] E. Schiebold, Neues Jahrb. f. Min., Abt. A. Beil.-Bd. 64 (Festschrift Brauns), pp. 251-320, 1931.

[11] W. H. Taylor, Z. Krist., **85**, 425, 1933.

hedry; for the Al : Si ratio is always 1 : 3 so that the 16 (Al + Si) atoms . . . must really be divided into four groups of which three contain 4 Si each and one contains 4 Al. This is possible either if the symmetry is triclinic or if it is monoclinic but not holohedral."

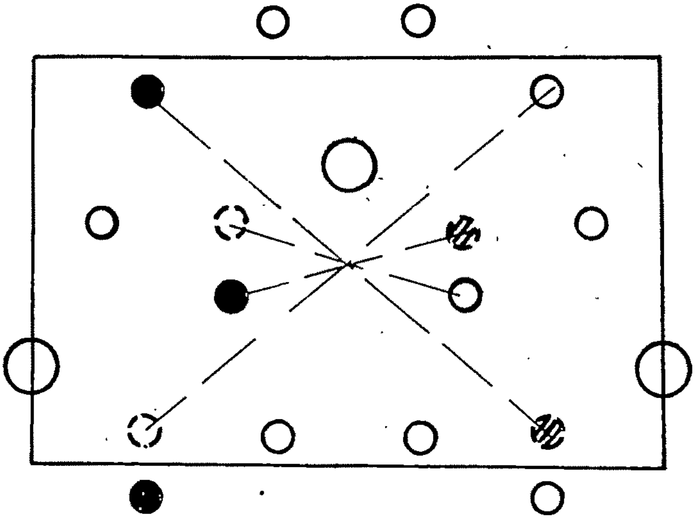

Fig. 4. Proposed structure of microcline (triclinic) with Si and Al in their several individual positions. Same portion of the unit cell as in Fig. 3. Large circles = K. Small open circles = Si. Small solid circles = Al. In this variant of structure Al is not distributed all over the available positions but is concentrated at two two-fold positions so as to make the structure triclinic. The monoclinic reflection plane has disappeared but the center of symmetry still exists.

The structure of Taylor seems thus to be inconsistent with previous results of crystallographic measurements which are all in favor of a holohedral symmetry of orthoclase.

The explanation which will now be offered for consideration is, however, able to remove this discrepancy, and furthermore it suggests a very interesting relationship between orthoclase and microcline. It is based on the principle of variate atom equipoints. A unit cell which contains different atoms at structurally equivalent points has been referred to as a cell with variate atom equipoints.[12] And although this is a comparatively new conception in crystallography, it has already been possible to demonstrate that variate atoms occur in the space-lattices of quite a number of chemical compounds. Since it has been shown that silicon and aluminum are mutually replaceable in certain mixed crystals, it follows that the alumino-silicates are compounds that are likely to furnish cases of variate atom equipoints.

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[12] T. F. W. Barth and E. Posnjak, J. Wash. Acad. Sci., 21, 255, 1931.

In the feldspar lattice both silicon and aluminum have coördination number four, and there are no structural features demanding that at all temperatures one particular pair of the available positions should be preferred by aluminum. And furthermore, we know that silicon and aluminum do occur as variate atoms in certain positions in the lattice of the plagioclase feldspars;[18] therefore why should they not also occur in the same fashion in the structure of orthoclase?

With reference to Fig. 3 it is seen that if silicon and aluminum together occupy the available positions of the unit cell (i.e., if they occur as variate atoms) the resulting symmetry will be monoclinic holohedral. If, however, the four aluminum atoms concentrate at two of those positions which in reference to the triclinic syngony are two-fold (as schematically shown in Fig. 4), the triclinic structure of microcline will result.

Indeed, if the crystal structure determination of Taylor can be relied on—and there is no reason for doubting the essential correctness of the structure—the conclusion that variate equivalent positions occur in the lattice of orthoclase seems practically inevitable. And thus this hypothesis explains very satisfactorily the structural relation between microcline and orthoclase.

More uncertain, however, is the theory accounting for the relationship between the two varieties of orthoclase (adularia and sanidine); the proposed hypothesis is in this case made probable simply by exclusion of all other possibilities. By the gradual change in adularia the optical properties are markedly affected (see Table II), and yet there is no distortion of the lattice, no displacement of the atoms, and no initiation of thermal rotation (the X-ray patterns of adularia and sanidine being identical) and so in our present state of knowledge the only remaining possibility is that an interchange of silicon and aluminum atoms takes place. This would affect the optical properties but would not generally show up in the X-ray pattern since Si and Al have approximately the same scattering power for X-rays. It is a matter of course that the interrelation of the silicon and aluminum atoms has to be such as to correspond to a monoclinic symmetry both in adularia and in sanidine. This is of course geometrically possible, but no data are available through which to suggest any actual arrangement.

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[18] Mixed crystals between albite and anorthite are formed because Al is able to partially replace Si in the feldspar lattice: $\mathrm{NaAl}\mathit{Si}\mathrm{Si_2O_8}$—$\mathrm{CaAl}\mathit{Al}\mathrm{Si_2O_8}$.

This case—though speculative—is theoretically interesting because it completes the survey of the various kinds of mechanism instrumental in polymorphic changes (see Table III).

TABLE III. Summary of the Mechanism of Polymorphic Changes.

	Mechanism	Name	Example
1.	A complete breaking up of the crystal lattice	Polytypy	Quartz-tridymite
2.	A dislocation of all or some of the atoms, with or without thermal rotation as accompanying phenomenon	Polysyngony	α-cristobalite-β-cristobalite KNO_{3I}-KNO_{3III}
3.	An initiation of thermal rotation not accompanied by any dislocation of atoms	Polytropy	Gradual transition in $NaNO_3$
4.	A redistribution of chemically different atoms whereby the geometrical points of the lattice remain unchanged. In certain cases the atoms may redistribute themselves so as to impart to the lattice a different syngony, whereby a very slight deformation may occur	Polysyngony	Orthoclase-microcline (?)
4′.	Or the atoms may redistribute themselves without changing the syngony of the lattice	Polytropy	Adularia-sanidine (?)

With reference to the table it can be added that if anything happens to the crystalline lattice of a compound the constituent atoms must move around in some way. Any dislocation of the geometrical positions is covered by the first three cases shown in the table, and any redistribution of the atoms within the same geometrical positions is covered by the cases 4 and 4′, and thereby all possibilities seem to be exhausted. Differences in the structure of the atoms would not in themselves mean changes in the crystalline lattice, neither would they manifest themselves as polymorphic changes unless accompanied by alterations of the lattice.

APPENDIX:

HISTORICAL COMMENTS.

Polymorphism. Since Mitscherlich in 1821 discovered the property possessed by certain compounds of assuming different crystal forms under different thermodynamical conditions this phenomenon has been given various names,[14] polymorphism (Dumas, 1836), heteromorphism (Berzelius, 1841),[15] paramorphism (Scheerer, 1854), and physical isomerism (Carius, 1863; O. Lehmann, 1877).

Polysyngony, as defined by the present author, was first recognized by Scacchi[16] and was introduced under the name of polysymmetry. As distinct from polymorphism, Scacchi regarded polysymmetry as a phenomenon by which the symmetry of the faces of a crystal is altered although the original form is retained. Soret (op. cit.), however, introduced the word "syngony" as pertaining to the geometrical symmetry. Excerpt: "Pour abréger et eviter les confusions, nous donnerous dans ce qui suit le nom de syngonie à la symétrie geometrique de l'orientation des faces possibles, et reservons le nom de symétrie physique de la structure interieure." This usage was adopted by Fedorov (op. cit.), who, in discussing Scacchi's considerations, further states:

> "Polysymmetrie würde . . . jedenfalls nur als eine besondere Art des Polymorphismus aufzufassen sein . . . das Wort muss durch Polysyngonie ersetz werden, ohne dabei die Priorität der Aufstellung des betreffenden Begriffes anzurühren."

Polysymmetry of Scacchi is thus different from the polysymmetry defined in the present paper, and to make things worse Groth[17] has later used the same word to designate still another phenomenon, viz., the fact that a regularly repeated twinning of submicroscopically small units can give rise to an apparently homogeneous crystal with higher symmetry properties than those of the twin units.

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[14] For the history and development of the conception of polymorphism, see A. Arzruni, Physikalische Chemie der Krystalle, Braunschweig, 1893.

[15] According to Tschermak, "heteromorphism" and "polymorphism" are not synonyms: "Die Substanz $CaCO_3$ ist dimorph, die Minerale Kalkspath und Aragonit sind heteromorph." (Lehrbuch der Mineralogie. Wien, p. 244, 1888 and later editions.)

[16] A. Scacchi, Della polisimmetria dei cristalli. Mem. R. Accad. Sci. Napoli, 1863. See also F. Zambonini, Z. Krist., **46**, 4, 1908.

[17] P. Groth, Einleitung in die Chemische Krystallographie. Leipzig, p. 2 ff., 1904.

There seems, however, to have been no demand for this application of the word, for two reasons. First, the same phenomenon had been recognized and named at least three times before, as follows:

(1) 1879 Tschermak called it "mimesy"[18]
(2) 1882 Mallard called it "apparent polymorphism"[19]
(3) 1890 Wyrouboff called it "pseudosymmetry."[20]

Second, the word polysymmetry had already been used by Scacchi with a totally different meaning.

It is unfortunate that many crystallographers after Groth have adopted his terminology; it is unfortunate because the name is superfluous, inappropriate for the phenomenon it is supposed to describe, and likely to cause confusion. A designation like that of Mallard, "apparent polymorphism," is self-explanatory and should be fully adequate.

The fact remains, however, that the word "polysymmetry" has now permeated the crystallographic literature so thoroughly that it seems impossible to re-define it without provoking a disturbing innovation, and in view of this an entirely new word, *polytropy*, is chosen. This selection would at least insure that the three names thus far adopted, "polytypy," "polysyngony," and "polytropy" would be unlikely to confuse the novice or vex the expert.

SUMMARY.

The physical behavior of a polymorphic change depends on the special manner in which the atoms in the crystal lattice rearrange themselves. The accompanying phenomena of the various inversions are therefore causally related to the structural differences encountered in the several modifications. Based on these facts an improved classification of polymorphic manifestations has been developed (see Table I, p. 275).

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[18] G. Tschermak, "Krystalle welche aus Individuen niederer Symmetriegrades polysynthetisch aufgebaut sind und äusserlich höhere Symmetriegrade darbieten . . . werden mimetisch genannt." Z. Deutsch. geol. Gesell., **31**, 637, 1879. At the same time A. Schrauf used "polydymie" in a rather similar sense. Z. Krist., **4**, 1, 1879.

[19] E. Mallard, ". . . dimorphisme apparant . . . est dû simplement à des groupement régulières et submoléculaires d'un reseau dissymétrique." Bull. soc. min. France **5**, 216, 1882.

[20] G. Wyrouboff (op. cit.) uses two terms, "assemblage pseudosymétrique" if the twin units are visible, and "corps pseudosymétriques" if the twin units are submicroscopically small.

The types of the mechanism of all theoretically possible cases of polymorphic changes have been explained and each case illustrated by actual examples (see Table III, p. 283).

The polymorphism of potash feldspar has been specially treated. Notwithstanding the fact that apparently monoclinic alkali feldspars composed of submicroscopically twinned triclinic units do occur in nature it can be shown that potash feldspar is trimorphous. The structural relationship between orthoclase and microcline has been tentatively established, based on the highly probable assumption that variate atoms occur in some of the equivalent points of the orthoclase lattice.

ACKNOWLEDGMENT.

The author is indebted to Doctors F. C. Kracek and George Tunell for valuable discussions of the subject treated.

Geophysical Laboratory,
Carnegie Institution of Washington,
October, 1933.

COMPOSITION OF A PART OF THE IDAHO BATHOLITH IN BOISE COUNTY, IDAHO.[1]

ALFRED L. ANDERSON AND ALFRED C. RASOR.

INTRODUCTION.

There has been no systematic study of the Idaho batholith, one of the greatest intrusive masses of the North American continent, except for certain small areas, since the batholith first attracted attention of geologists more than 40 years ago. In most of the earlier reports the rock has been described as quartz monzonite and granite, and this has given rise to the widely accepted view that the batholith is prevailingly quartz monzonite. It has since been found that these earlier more or less cursory studies over widely scattered parts of the batholith have been only in part truly representative and that subsequent more detailed quantitative studies indicate a much more variable composition with part of it as calcic as granodiorite and quartz diorite.

This paper is part of a comprehensive investigation of the Idaho batholith in an effort to learn more of its character and genesis, and deals specifically with its composition in a part of the mountainous area drained by the Boise and Payette rivers in the middle-southwestern part of the state (Fig. 1). More than 1200 square miles of the batholith were examined and specimens for detailed microscopic study were collected from more than 50 localities. These are from one of the most deeply eroded parts of the batholith, where not even traces of roof pendants remain.

There are other intrusives in the region, especially along great shear zones in the batholith, but these intrusives, including dikes of diorite and several kinds of porphyry, are much younger than the batholith and have no bearing on the present problem. Differentiates related to the batholith are scarce, and discussion of them will be reserved for papers dealing with the genesis of the batholith.

Each of the specimens of granitic rock was studied in detail by means of microscopic examination of thin sections, proportions of the minerals were estimated from Rosiwal analyses, and the mode of each was then plotted graphically, using the triangular diagram of Johannsen.[2] This study discloses that for this part of the batholith the rock is more calcic than indicated in earlier much generalized descriptions, and belongs to two distinct facies which are megascopically and microscopically distinguishable.

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[1] Published by permission of the Director, U. S. Geological Survey, and the Director, Idaho Bureau of Mines and Geology.

[2] Johannsen, A., "On the representation of igneous rocks in triangular diagrams," Jour. Geol. Vol. XXX, pp. 167-69, 1922.

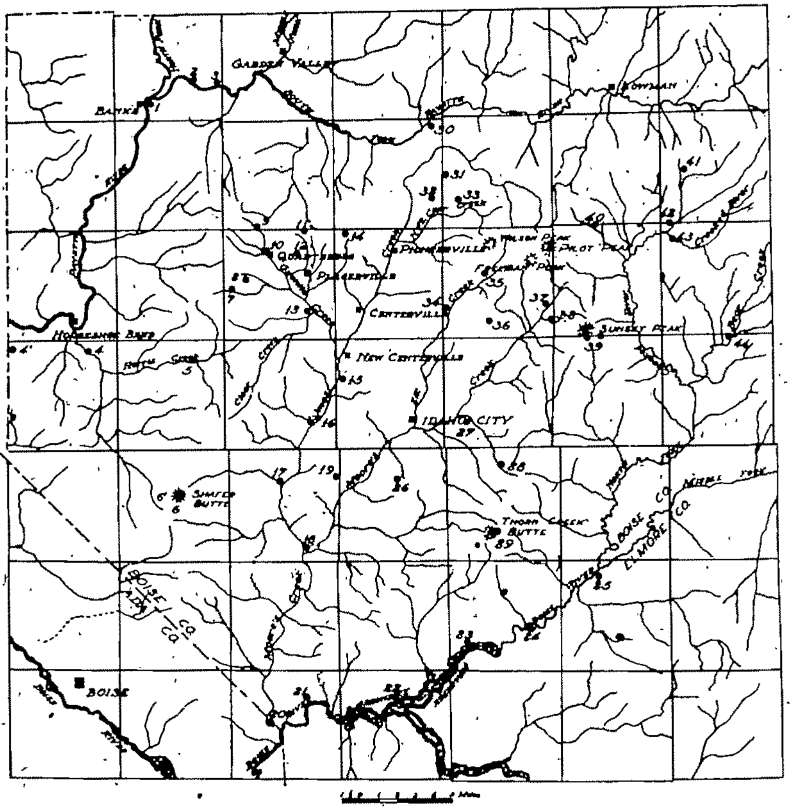

Fig. 1. Sketch map showing localities from which rock specimens were collected.

PREVIOUS ROCK DESCRIPTIONS.

These rocks were first described by Lindgren[3] as largely a typical coarse-grained granite composed of gray quartz, white or reddish feldspar—partly orthoclase, partly a sodic plagioclase—small biotite flakes, rarely hornblende, locally muscovite, and accessory ilmenite, apatite, zircon, garnets, titanite, and

[3] Lindgren, Waldemar, "The mining districts of the Idaho Basin and the Boise Ridge, Idaho," U. S. Geol. Surv. Eighteenth Ann. Report, Pt. III, pp. 630-631, 681-682, 707-710, 1896-1897.

monazite. He also pointed out that this rock was by gradual transition connected with rocks intermediate between granite and diorite, and described as a local modification a rock in the Willow Creek district several miles southwest of Horseshoe Bend that was more closely related to a quartz-mica-diorite than to a granite, and was very similar to the granodiorite of the Sierra Nevada batholith in California.

Jones[4] later gave a more generalized description of the typical rock and stated that within the Boise Basin it showed very little variation in composition and lithologic character and was to be classed as granite. Ballard[5] also described the rock in the same locality as a true biotite granite. Since then, Ross[6] has examined the rock in a part of the Boise Basin near Quartzburg and he points out that it resembles that of the same mass elsewhere in the State and is a light-gray, rarely pinkish, moderately coarse-grained rock whose average composition is that of a somewhat calcic quartz monzonite, with local more calcic and more silicic variations. In most places, according to Ross, it contains about 40 per cent of oligoclase, 20 to 40 per cent microcline, 15 to 30 per cent quartz, and 3 to 10 per cent mica (mostly biotite), and most of the rock has a typical granitic texture, with an average grain diameter of three millimeters.

PRESENT ROCK DESCRIPTIONS.

The present study covers much of the region earlier described by Lindgren, but also extends over a greater area to the east and north. It includes too the relatively small areas described by Jones, Ballard, and Ross, in Boise Basin.

It is convenient to treat the rocks of this area as consisting of two main facies, one to be described as the darker facies and the other as the lighter. Each has a rather distinctive assemblage of minerals and more or less distinctive textures, and it is plain that the darker facies is somewhat older than the other and has in part been invaded by it. The darker facies is much like that described as the marginal rock[7] of the batholith in the north-central part of the State and probably occupies an analogous position here, although the actual margin has not been observed, but probably lies to the west beneath younger Tertiary and Quaternary formations.

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[4] Jones, E. L., Jr., "Lode mining in the Quartzburg and Grimes Pass porphyry belt, Boise Basin, Idaho," U. S. Geol. Surv. Bull. 640-e, p. 90, 1916.

[5] Ballard, S. M., "Geology and gold resources of the Boise Basin, Boise County, Idaho," Idaho Bureau of Mines and Geology Bull. 9, p. 19, 1924.

[6] Ross, C. P., "Some lode deposits in the northwestern part of the Boise Basin, Idaho," U. S. Geol. Surv. Bull. 864-d, in preparation.

[7] Anderson, A. L., "Geology and mineral resources in the region about Orofino, Idaho," Idaho Bureau of Mines and Geology Pamphlet 34, pp. 17-23, 28-29, 1930.

Darker Facies.

The darker facies lies mainly along the west side of the exposed batholith, particularly west of Garden Valley (Fig. 1) and at and west of Horseshoe Bend. Specimens were collected at localities 1, 2, 3, 4, and 4′ (described by Lindgren) and along the North Fork of the Payette River from three to 20 miles north of Banks. Those along the North Fork are beyond the borders of the index map, but their modes, 45, 46, 47, and 48, are shown in Figure 2. Small areas of more or less similar rock also lie well to the east within the main area of lighter colored rock, particularly on the ridge southwest

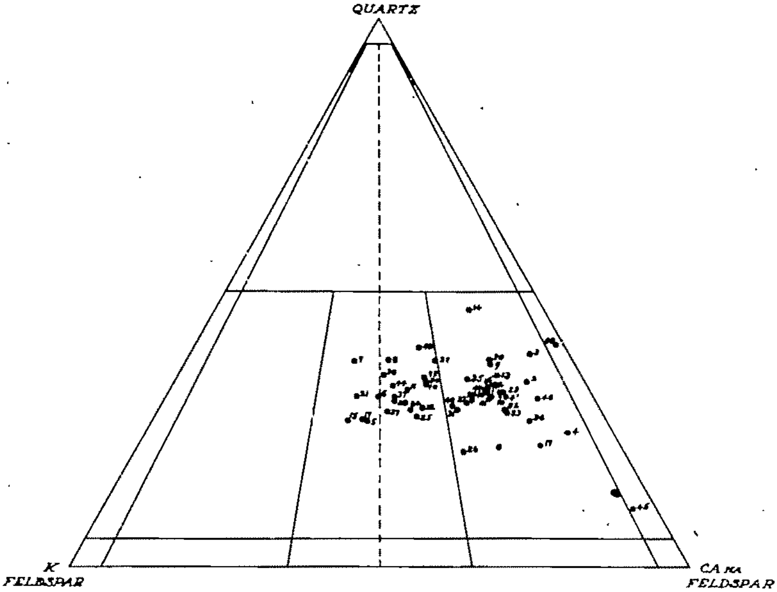

Fig. 2. Diagram (after Johannsen) illustrating the mode of each rock. Includes Class I and Class II rocks. Those falling in the central section are quartz monzonites, those in the large division on the right are granodiorites, and those in the narrow division at the right margin are quartz diorites. The empty sections on the left of the quartz monzonite would contain granite.

of Idaho City (19) and along part of the Boise River (22 and 23).

Most of the rock comprising the darker facies is usually somewhat gneissic, but otherwise is like normal granitic rock. It is only moderately gray, but somewhat darker than the rock composing the main mass of the batholith. It shows little variation in grain diameter, the average light-colored grains ranging from four to seven millimeters and the dark about half as large. Most of the rock is more or less hornblendic, although hornblende never exceeds biotite, and it commonly contains an unusually high percentage of visible titanite grains.

Most of the facies has the composition of granodiorite, near quartz diorite, but there are also parts as calcic as quartz diorite. It will be observed in Figure 2 that most of the modes are well to the right in the diagram. It is not possible to distinguish these variations megascopically.

A complete list of the rock minerals includes andesine, quartz, biotite, microcline, hornblende, titanite, allanite, magnetite, zircon, apatite, epidote, chlorite, muscovite, zoisite, and minute flakes of secondary white mica. Most of the minerals show very complex interlocking and interpenetrating relationships as evidence of a complex origin, but their detailed description and interpretation is not within the scope of this paper. The biotite occurs in irregular or ragged penetrating leaves, the quartz and microcline also as irregular penetrating and interlocking grains, and the andesine as poorly bounded crystals. Only the accessory minerals commonly have regular crystal outlines.

Andesine, quartz, biotite, and microcline are the essential minerals and variations in proportions are mainly between the andesine and microcline. Andesine is the most abundant and composes from 40 to 75 per cent of the rock, with an average near 50 per cent. The quartz content is ordinarily rather high and ranges between 20 and 35 per cent, with an average near 28 per cent. Microcline ranges from less than 5 per cent to 15 per cent, with an average near 7 per cent. It cannot be safely distinguished from the andesine crystals, except microscopically, and its abundance, and therefore the classification of the rock cannot be judged from the hand specimen. The average biotite content is about 10 per cent. Hornblende, although rarely absent, is usually much subordinate and commonly forms less than 1 per cent of the rock, but may increase to 5 per cent. The biotite and hornblende together make up from 7 to 14 per cent of the rock and the facies, therefore, belongs in Class II of Johannsen's quantitative mineralogical classification.[8] The abundance of titanite in rock of this facies received early comment by Lindgren. Its yellowish-brown crystals are plainly visible in the hand specimens and comprise as much as 2 and 3 per cent of the rock. Epidote, too, is equally abundant and is usually megascopically visible in fairly large grains in the feldspar and biotite. Both titanite and epidote are characteristic features of the facies.

Neither the biotite nor the hornblende show other than ordinary optical characters. They are rarely altered except to epidote, but in some grains the alteration is nearly complete and extends into adjacent feldspar crystals. The andesine is usually only slightly zoned and has an average composition of about $Ab_{65}An_{35}$. It is more highly zoned, however, in the rock southwest of Idaho City (19) and along the Boise River (22 and 23) and has borders of oligoclase. All plagioclase grains throughout the facies, except where hydrothermally altered, are exceptionally clear and show only slight and irregular secondary conversion to white mica, but may contain considerable epidote usually in large grains. Most of the microcline has a distinct plaid structure, but in some grains the structure is only partly formed or even fails to show. Either feldspar may have an occasional fair sized grain of muscovite and scattered zircon, apatite, and magnetite crystals. Zoisite grains are relatively abundant and are embedded in the plagioclase or in the biotite. Chlorite is rare and is then secondary after biotite. Titanite and allanite occur in or cut all minerals except the quartz.

Lighter Facies.

The lighter facies extends eastward from Garden Valley and Horseshoe Bend, and, except for certain local occurrences of the darker facies already mentioned, continues far beyond the borders of the map area. It forms what has been called the main "core" of the batholith or the prevailing "inner facies."

This rock in contrast with that composing the darker facies is rarely, if ever, gneissic and contains no visible titanite and hornblende. It is light gray, usually appreciably lighter than the rock in the other facies, for it has only about half the quantity of dark minerals. Its grain size is about the same as the other. Much of the rock is uniformly grained and has a typical granitic texture, but there are also large areas, for example, between New Centerville, Quartzburg, and Horseshoe Bend, where the rock is porphyritic with embedded microcline phenocrysts measuring up to 30 millimeters, and there are also parts with a plainly saccharoidal appearance.

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[8] Johannsen, A., "Suggestions for a quantitative mineralogical classification of igneous rocks," Jour. Geol. Vol. XXV, pp. 63-97, 1917, and "A quantitative mineralogical classification of igneous rocks, revised," Ibid, Vol. XXVIII, pp. 38-60, 159-77, 210-32, 1920.

Most of the rock of this facies is a granodiorite or calcic quartz monzonite, and falls mainly in the calcic part of the quartz monzonite division (Fig. 2) and in the adjacent granodiorite section. In general the granodiorites are more alkalic and lie to the left of those representing the granodiorite of the darker facies. It is not possible to distinguish between the granodiorite and quartz monzonite in the even-grained rock, except microscopically. The porphyritic rocks, however, are most commonly quartz monzonites, and porphyritic character may serve as a useful criterion for distinguishing these otherwise unmappable types in the field.

The mineral list does not differ materially from that for the darker facies, but includes quartz, oligoclase, microcline, and biotite as the chief essential minerals, muscovite as a subordinate mineral, zircon, allanite, magnetite, apatite, and garnet as accessories, and chlorite, zoisite, rarely epidote, and sericitic mica as secondary minerals. The chief difference is in the composition of the plagioclase (oligoclase in place of andesine), in a very notable scarcity of epidote, titanite, and hornblende, and a relatively large increase in muscovite and chlorite. The rock possesses a granitic texture and the shapes and arrangement of the grains are like those in the more calcic facies, although departures are toward more imperfect shapes and in two localities (28 and 39) the texture is closely aplitic. Phenocrysts in the porphyritic rock appear to have fair crystal outline, but thin sections reveal irregular penetrating borders.

Oligoclase is usually the most abundant mineral and composes about 40 per cent of the rock, although its content in the different specimens ranges from as low as 25 per cent to as high as 57 per cent. The quartz content is also generally high, ranging from 20 to 43 per cent, and averaging near 30 per cent. Some of the quartz grains measure up to eight millimeters and locally dwarf other minerals. The oligoclase and microcline cannot be distinguished in the hand specimen, except where the microcline occurs as phenocrysts in the porphyritic rock. In the latter the phenocrysts may comprise from 10 to 30 per cent of the rock and range from 10 to 30 millimeters in longest dimension. In general the microcline content ranges from about 12 to 40 per cent, but mostly between 15 and 30 per cent. The biotite content is low and averages about 4 per cent, but limits range from 2 to about 8 per cent. Most of the rock, therefore, contains less than 5 per cent of dark minerals and belongs in Class I of Johannsen's quantitative mineralogical classification.[9] Muscovite is usually visible in the hand specimen and comprises from less than 1 per cent to as much as 6 per cent of the rock. No other minerals are megascopically visible.

Biotite is usually in very ragged grains and more or less completely altered to chlorite with liberation of small magnetite crystals. The oligoclase exhibits only slight zoning, or none at all, and has a composition of about $Ab_{84}An_{16}$. It usually shows excellent polysynthetic twinning, but the twinning may become indistinct in grains that are considerably sericitized. In general the feldspars are much more extensively and uniformly altered than in the darker facies. The phenocrystic microcline is commonly Carlsbad twinned, but smaller irregular grains are usually not. Most of the microcline has its characteristic plaid structure, but in some grains the structure is only partly formed or may be entirely invisible.

CONCLUSIONS.

The fact that the Idaho batholith in the general region, including the Boise Basin, is composed of two distinctive facies, each characterized by certain mineral assemblages and textures, has not heretofore been recognized. These facies are rather easily distinguished, the older by its darker color and foliation, and by its andesine, hornblende, and conspicuous titanite and epidote grains, the other by its lighter color and usual absence of foliation, and by its oligoclase, muscovite, chlorite and absence of titanite. It is not, however, possible to distinguish the compositional variations in each of the facies, except microscopically. The darker facies ranges between calcic granodiorite and quartz diorite, and the lighter between granodiorite and quartz monzonite. As a whole, the rock is much more variable in composition and much more calcic than inferred in earlier descriptions.

[9] Jour. Geol., Vol. XXV, op. cit., pp. 63-97, idem, Vol. XXVIII, op. cit., pp. 38-60, 159-77, 210-32.

UNIVERSITY OF IDAHO,
SCHOOL OF MINES,
MOSCOW, IDAHO.

MIDDLE CAMBRIAN FOSSILS FROM KASHMIR.

TEIICHI KOBAYASHI.

(Scientific results of the Yale North India Expedition: Reports on Himalayan Stratigraphy.)

During the Yale North India Expedition of 1932-1933, Dr. Hellmut de Terra of the Peabody Museum of Yale University made a collection of Cambrian fossils from Handawara, Kashmir. The locality lies in the northwestern portion of the Kashmir Valley, five miles from Handawara (Handawor), on the road to Zachaldor in the Talar Valley. The fossils were collected between Turkapur and the bend of the Talar River in a green phyllitic shale with ferruginous patches. The locality can be found on the Survey of India sheet No. 43 ŏ/3 C2. In view of the fact that up to this time only one occurrence of fossiliferous Cambrian had been located in the Himalayas, namely, in Spiti, this new find is of importance.

The fossils were transferred to me for study upon the suggestion of Prof. Percy E. Raymond of the Museum of Comparative Zoology at Harvard University. I here express my cordial thanks to these students for the privilege of working upon such an interesting collection, and also to Dr. C. E. Resser for permission to illustrate a specimen of *Oryctocephalus* for the purpose of comparison.

The fossils in question are embedded in a greenish-gray shale. Through pressure, probably connected with the rock folding, they have been strongly compressed and deformed secondarily. Fortunately, however, the abundance of specimens makes it possible to ascertain the original form. A characteristic of this fauna is the small number of species to be found among the large quantity of individual specimens.

The collection contains only three species of trilobites, i.e., *Agnostus* cfr. *rakuroensis* Kobayashi, *Tonkinella breviceps* Kobayashi and *Anomocarella memor* (Reed), in addition to fragments of linguloids and hyolithoids. The linguloids are too poor for any precise work; the hyolithoids are triangular pyramids with an apical angle of 12 degrees. The carination on the ventral side of the latter suggests that this form might be close to Reed's *Hyolithes* aff. *danianus*[1] found in the equivalent horizon of Spiti.

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[1] Reed, Cowper, The Cambrian Fossils of Spiti (Mem. Geol. Surv. India, ser. XV, Vol. VII, Mem. No. 1), p. 48, Pl. VI, fig. 4, 1910.

Notwithstanding the small number of species, this trilobite fauna is very interesting, because it extends the western limit of the Stephen fauna of British Columbia. Recently I found an exact equivalent of the Stephen fauna in South and North Chosen. The assemblage is well characterized by such distinguishing genera as *Olenoides* (i.e. *Neolenus*), *Oryctocephalus* and *Tonkinella*. The last genus has hitherto been foreign to the original Stephen fauna, but I found it in Walcott's undescribed collection in the U. S. National Museum, which was secured from the Stephen formation, probably its middle or upper portion, on Mt. Stephen, British Columbia, and I described the form under the name of *Tonkinella stephenensis*.[2] The genus was originally described by Mansuy[3] from the *Tonkinella flabelliformis* zone of Siao-pin-tchai.

Oryctocephalus, on the other hand, is distributed in the Stephen formation of British Columbia, and in the contemporaneous formations of Nevada and Idaho.[4] It also occurs in the Templeton fauna of Mt. Isa, Queensland, Australia, and in horizons 2 and 9 of the Parahio series of Spiti, India.[5] *Anomocarella memor* suggests that the *Tonkinella* horizon of Handawara is close to horizon 9, instead of 2, of the Parahio, because it occurs more frequently there, and it is also closely related to *Anomocarella temenus* of eastern Asia, which is a very common fossil in the *Olenoides* zone of Chosen.

As a result, the fauna of Handawara is considered to be contemporaneous, or at least approximately so, with those of horizon 9 of the Parahio series, the *Tonkinella flabelliformis* zone of Indo-China and adjacent Yunnan, the *Olenoides* zone of Chosen, the Stephen formation of western North America, and also probably the Templeton formation of Mt. Isa, Queensland. Therefore Dr. de Terra's collection adds a substantial link to the chain of correlations tying together the Middle Cambrian formations throughout the Pacific realm. Further discussion on the correlation of the Cambrian strata of this major province will be presented in the stratigraphical part of my monograph, "Cambro-Ordovician of South Chosen."

[2] Kobayashi, T., Cambro-Ordovician Formation and Faunas of South Chosen, Paleontology, Pt. III, Cambrian Faunas of South Chosen (Jour. Fac. Sci. Imp. Univ. Tokyo, Sect. I). In print.

[3] Mansuy, H., 1916, Faunes Cambriennes de l'Extrême-Orient Méridional (Mém. du Serv. Géol. de l'Indochine, Vol. V, Fasc. I), p. 43, 1916.

[4] Walcott, C. D., Second Contribution to the Studies on the Cambrian Faunas of North America (Bull. U. S. Geol. Surv. No. 30), p. 211, etc., 1886.

[5] Reed, op. cit., 1910.

Family AGNOSTIDAE M'Coy.

Subfamily AGNOSTINAE Jaekel.

Genus *Agnostus* Brongniart, 1822.

Agnostus cf. *rakuroensis* Kobayashi.

Pl. I, fig. 1.

Cf. *Agnostus rakuroensis* Kobayashi, Cambro-Ordovician Formations and Faunas of South Chosen, Paleontology, Pt. III, Cambrian Faunas of South Chosen.

Only a solitary cephalon was found in this collection.

Cephalon subquadrate with round angles, 1.3 mm. long, 1.6 mm. wide and surrounded by a convex brim and deep marginal groove; glabella two-thirds as long as the cephalon, subconical, rounded in front and back, elevated above the side-lobes, divided into a short anterior and long posterior lobes by a transverse furrow; the convexity of the glabella increases toward a certain point at a short distance from the articulating margin which corresponds to the highest point of the cephalon, and from there it decreases gradually toward the margin; relatively small triangular lobes located on both sides of the base of the glabella; no axial groove found in front of the glabella.

A pit is found at the median point of the frontal groove and represents the initial part of the preglabellar longitudinal groove. Two pairs of pits are observed along the sides of the posterior axial lobe, but it is not certain whether they are original, or are secondary injuries. No tubercles have been found on the glabella.

Without the pygidium it is difficult to arrive at the specific identification for such an agnostid, but so far as the cephalon is concerned, there is no objection to its reference to *Agnostus rakuroensis*. This form is similar to *Agnostus spitiensis* Reed[6] and *A. coreanicus* Kobayashi but differs from them in the absence of the median tubercles on the axial lobe. The distinction from *Agnostus chinensis* Dames[7] (not Walcott), to which it is also close, is found in the absence of the axial furrow across the preglabellar slope.

A cephalon referred to *Agnostus chinensis* by Walcott,[8] with some differences noted, may also be of this species. *Agnostus*

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[6] Reed, Cowper, Cambrian Fossils of Spiti, p. 4, Pl. I, figs. 1-3, 1910.

[7] Dames, In Richthofen's China, Bd. IV, p. 27, Pl. 2, figs. 18-19, 1883.

[8] Walcott, Cambrian Faunas of China, p. 7, fig. 5c, 1913.

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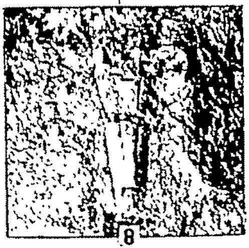
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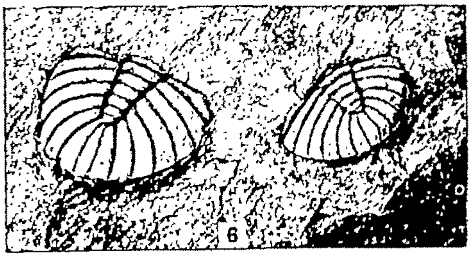
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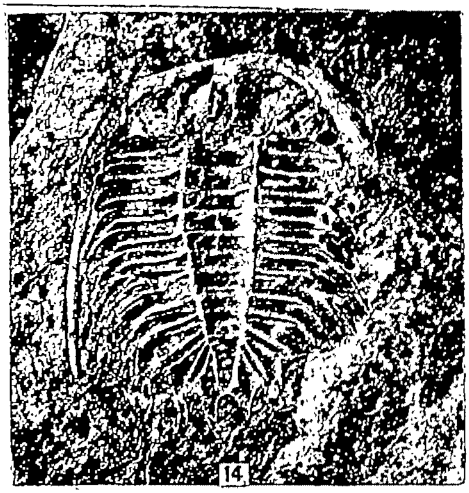
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douvillei Bergeron[9] has the same kind of cephalon, but the marginal border is much wider and less convex.

Formation and locality: Middle Cambrian shale of Handawara in Kashmir. This species is distributed in the *Olenoides* zone of Chosen and also in the black shale of the early Middle Cambrian in the Chuwa area together with *Ptychoparia ? coreanica* Kobayashi. Walcott's *A. chinensis,* referred to above, was procured from the lower shale of the Kiulung group, 3.2 km. south of Yen-chuang, Sintai district, Shantung.

Family ORYCTOCEPHALIDAE Raymond.

Subfamily ORYCTOCEPHALINAE Beecher.

This comprises *Oryctocephalus* Walcott, 1886, *Oryctocare* Walcott, 1908, and *Tonkinella* Mansuy, 1916.

Genus *Tonkinella* Mansuy, 1916.

Tonkinella Mansuy, Faunes Cambriennes de l'Extrême-Orient Méridional (Mém. Serv. Géol. de l'Indo-Chine, Vol. V, Fasc. 1), p. 43.

Tonkinella Kobayashi, Cambro-Ordovician Formations and Faunas of South Chosen, Paleontology, Part III, Cambrian Faunas of South Chosen.

Genotype: *Tonkinella flabelliformis* Mansuy.

When Mansuy established this genus he presented only the description of *Tonkinella flabelliformis*, instead of giving a generic diagnosis. *T. flabelliformis* is, however, represented only by incomplete cranidia and complete pygidia. A nearly complete carapace of *T. stephenensis* Kobayashi, lacking only the free cheek and hypostoma, has fortunately been collected from the Stephen formation of Mt. Stephen, British Columbia, and is now kept in the U. S. National Museum. In the paper cited above, I have already furnished the diagnosis of this

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[9] Bergeron, Étude de quelques trilobites du Chine (Bull. Soc. Géol. France, 3e sér., Vol. XXVII), p. 43, Pl. 12, fig. 3, 1889.

Fig. 1. *Agnostus* cf. *rakuroensis* Kobayashi. x 6. Cat. No. 14337, Y.P.M.

Figs. 2-6. *Tonkinella breviceps* Kobayashi. x 3. Cat. Nos. 14327, 14330, 14335, Y.P.M.

Fig. 7. *Lingulella* ? sp. x 3.

Fig. 8. *Hyolithes* sp. x 3.

Figs. 9-13. *Anomocarella memor* (Reed). x 3. Cat. Nos. 14328, 14337, 14334, 14332, 14336, Y.P.M. Fig. 11 shows the secondary deformation of two cranidia. All collected from Kashmir.

Fig. 14. *Oryctocephalus reynoldsi* Reed, from the Spence shale of Danish Flat near Liberty, Idaho, showing the hypostoma. x 3.

genus on the basis of *T. flabelliformis* supplemented by *T. stephenensis*.

Among the Himalayan material are found two hypostomata of *T. breviceps* which, as a new addition to the generic characters, will be discussed in detail in the specific description.

Worthy of notice is the marvelous resemblance between this hypostoma and that of *Oryctocephalus reynoldsi*, which will serve as evidence to prove the close relationship between *Tonkinella* and *Oryctocephalus* as already pointed out by me. The hypostoma of the latter was found among the collections at the U. S. National Museum and is illustrated here for comparison, it in itself also being a find new to science.

Geological and geographical distribution: Middle Cambrian of southern and eastern Asia and western Canada.

Tonkinella breviceps Kobayashi.

Pl. I, figs. 2-6.

Tonkinella breviceps Kobayashi, ibid.

Cranidium broad; glabella and fixed cheek, measured across the eyes, approximately the same in breadth; glabella long, slightly expanded forward and well defined by deep dorsal furrows; three pairs of glabellar furrows and an occipital furrow, all strong, the first and second pairs dying out on the axis of the glabella, the rest going across it; eyes opposite the first and second glabellar lobes, and connected with the glabella by ocular ridges; no frontal limb; frontal margin broadly rounded; frontal rim narrow, strong and sharply ridged; facial sutures subparallel anterior to the eyes, and short and diagonal posterior to them.

No free cheek.

Hypostoma subquadrate, with triangular lateral wings produced at the extremities of the anterior margin; its postero-lateral corners obliquely truncated, and inside of it a pair of maculae are located.

Thoracic segments sharply spined postero-laterally at the extremities; pleural groove running transversely across the middle of the pleura.

Pygidium semi-ovate; axial lobe narrow and short, tapering regularly backward and composed of six rings in addition to an articulating half ring; articulating pleural segment with a wide facet; pleural lobes divided into subequal flat ribs separated from one another by narrow deep grooves; excepting the articulating segment, thirteen pleural ribs are to be counted around the axial lobe; margin entire, provided with a very narrow brim which is separated from the pleural ribs by a narrow groove inside.

The largest cranidium and pygidium in the Himalayan collection are 5 mm. and 6.4 mm. in length respectively.

The surface texture can not be described, because the carapace has been altered secondarily.

The strength of the ocular ridge varies considerably among the cranidia. Four pairs of glabellar furrows are sometimes to be observed on the glabella and among them the first rudimentary pair is represented simply by pits located on both sides and close to the front of the glabella. The number of pleural ribs on the pygidium is constant for this species, the same number being found even on a small pygidium, 1.7 mm. long.

Formation and locality: Middle Cambrian shale of Handawara in Kashmir. This species is also known to occur in the *Olenoides* zone of Neietsu, Kogen-do, South Chosen, and of Chuwa, Heian-nando, North Chosen.

Family ASAPHISCIDAE Raymond.

Genus *Anomocarella* Walcott, 1905.

Anomocarella memor (Reed).

Pl. I, figs. 9-13.

Ptychoparia (Conocephalites) memor Reed, Cambrian Fossils of Spiti, 1910, pp. 31, 32, 68, Pl. IV, figs. 4, 5.

Cephalon, exclusive of a pair of long genal spines, semicircular; glabella two-thirds as long as the cranidium, truncato-conical, tapering forward slightly, elevated and surrounded by a circum-glabellar furrow of moderate strength; first and second glabellar furrows obscure, third and occipital ones fairly distinct; palpebral lobe large, opposite the middle of the glabella; ocular band wide and ocular ridge present; fixed cheek across the eyes narrower than the glabella; but expanded in its anterior and posterior limbs; frontal limb a little wider than rim, both gently convex and separated from each other by a shallow groove; facial sutures divergent forward and backward from the eyes with a gentle sigmoid curvature.

Hypostoma subovate and accompanied by antero-lateral wings; central body convex, elliptical, two-thirds as long as the hypostoma and defined by a groove; a pair of maculae located behind it.

Thoracic pleura a little longer than its axis and produced into a spine with a sharp change in direction backwards.

Pygidium semi-circular; axial lobe cylindro-conical, elevated, and consisting of about five segments; about five ribs can be counted in the gently inclined pleural portion and these merge into the narrow border.

The large cranidium attains 5.5 mm. in length; the large pygidium, 3.3 mm. in length.

Cowper Reed described this species from the cranidium only. Comparison between the present material and replicas of the cotypes kept in the U. S. National Museum shows a perfect agreement in shape and size, and therefore I have no hesitation in regard to the specific identification, except for one point. Reed's description states that the surface of the head-shield of the types is granulose, but none of the specimens now in hand reveal any distinct granulation; however, as the carapaces have been altered secondarily, very little of the texture can be made out with certainty. Then, too, the granulation is not clear even on the replicas which I examined.

Through the secondary deformation the frontal brim of the cranidium sometimes increases its convexity considerably, and at the same time the outline is greatly changed. However, the original form may be arrived at from a comparison of the two cranidia illustrated in figure 11, one of which is compressed laterally, the other posteriorly.

Comparisons: Among the Chinese forms, Reed compared this species to *Anomocare flava* Walcott. The former is, however, distinguished from the latter by the narrower and less convex marginal brim of the cephalon, and the narrower outline of the pygidium. *Anomocarella temenus* (Walcott)[10] is another allied species which again differs from this one by the broader and flat brim, and which usually grows to be three times as large. Mansuy's *Anomocare* cf. *megalurus*[11] from San-kia-tchai is extremely close to the present species, if not identical with it.

Formation and locality: Middle Cambrian shale of Handawara, Kashmir. Reed's specimens were collected from horizon 9 of the Parahio series on the Parahio River, Spiti.

The specimens are part of the Indian collection of the Peabody Museum of Natural History, New Haven, Connecticut.

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[10] Walcott, Cambrian Faunas of China, p. 206, Pl. 20, figs. 7, 7a-d, 1913.

[11] Mansuy, Faunes Cambriennes de l'Extrême-Orient Méridional, p. 37, Pl. VI, figs. 7a-c, 1916.

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DISCUSSIONS AND COMMUNICATIONS.

LAND AND SEA ON THE CANADIAN SHIELD IN PRECAMBRIAN TIME, H. C. COOKE.

Land and sea on the Canadian Shield in Precambrian time by H. C. Cooke (1) gives an excellent review of current opinion by one group of students of the geologic history of that remote period. It is to be regretted that Cooke has omitted not only opinions that differ from those which he elects to uphold but also all references to literature presenting alternate points of view. Some alternate interpretations of the geologic story should be considered along with Cooke's summary. These fall into two classes: the first includes certain general principles; the second group covers certain disputed conclusions of origin and structural relations of rocks. Inferred positions of land and sea in any specific period depends on the correctness and correctness of application of these general principles.

General Principles.

Definitions of periods such as Keewatin and Lower Huronian depart from custom followed in naming later ones. Also the assumption of derivation of sand for graywacke from a low mountainous area in maturity, and at another place, the use of petrographic similarity of fragments in sediments to rocks in place as criteria of origin superior to variation in texture, primary structure, and thickness are open to question.

Definition of periods. The periods of the Paleozoic and Mesozoic eras were assigned to cover a continuous time interval which was separated from later events by a definite break in the record. The periods were named after the locality where their place in the geologic sequence was recognized for a first time or by an outstanding characteristic of the rocks at such a place. Cooke defines the Keewatin (p. 429) as, "the first geological period of which we have any record on the Canadian Shield, the older part of the Archean, Archeozoic, or early Precambrian time." This is a time designation and not a type place designation. He adopts the same sort of designation for the term Lower Huronian (p. 436). If this procedure is acceptable, then any series recognized as older than the Keewatin is Keewatin because it is the oldest period of which we have any record. Perhaps on the same basis of definition we might say there can be no Precambrian and that everything below the Ordovician is Cambrian, or some of us might decide that we need not go back to even that remote period studied so industriously by Sedgwick.

If, as general precedence demands, use of the Keewatin is restricted to rocks of the type region and to others of similar age, cognizance must be given to Tolman's suggestion that the Keewatin is divisible into an upper and lower group (2a), to Moehlman's observation that a group of old sediments lies below the Keewatin rather than in it (3a), and to Bain's observation that the sediments lie nonconformably below the Keewatin in at least two places (4a). The reader would do well to read the literature on these early series and by reference to the maps, photographs, and figures weigh the evidence for himself.

Conditions of graywacke accumulation. The statement (p. 435) that, "above the (Timiskaming) conglomerates there are great thicknesses of thin bedded graywackes, implying deposition in fairly quiet waters" is offered in evidence that, 'the Timiskaming land mass was a low montainous area, eroded to maturity, with wide low valleys.' These graywackes carry original feldspar and ferromagnesian minerals, locally exceeding quartz in abundance. Weathering of the material before deposition therefore was slight, and this is not characteristic of extensive deposits of streams from a maturely dissected region, flowing in wide, low valleys. Rather the evidence gathered to date favors a mountainous source where fresh material was being exposed continuously, transportation too rapid for decay and solution during movement, and deposition on a wide piedmont where rapid burial protected the waste from active reworking. The same criticism applies to the statement (p. 438) that, "the entire series (Lower Huronian) was deposited in shoal water."

Criteria of source of sediments. The reader finds (p. 439), "It is a hypothesis supported by some geologists that coarse sediments thicken in the direction of their source; and if this is true in this instance, the area to the south and southwest, perhaps no great distance from the known areas of Mississagi quartzite, must have been a highland. Further reference to this question will be made on a later page." Thickening of sediments to southward is mentioned on p. 440, but the question of applicability of this hypothesis is never raised again.

Many geologists will question the general applicability of the above hypothesis; but coarsening of fragments as the formation thickens to a maximum has been very generally accepted as an indication that the source lies in the direction of the larger pieces. This is the expectable variation; for if a stream can carry a one-foot boulder it is not customary for it to deposit two-inch cobbles to the exclusion of all coarser material. The Bruce conglomerate becomes progressively coarser as the thickness increases southeastward (5a). Specific localities are listed in the above reference. Granite and granitic rocks of pre-Huronian age occur southward as well as northward of the area of sedimentation, and general composition of fragments in the Bruce conglomerate cannot be considered critical of location of origin.

Controversial Questions.

References to literature on controversial questions such as the Grenville-Huronian relations, Grenville-Keewatin relations, and the possibility that the Keweenawan may be later than the period of major folding which accompanied intrusion of the Killarney granite, are omitted completely. Enough evidence is available to indicate that more than one stand is tenable on these questions and that each individual must weigh the evidence in determining which he will take. His picture of the distribution of rising and sinking areas will be very different depending upon which viewpoint he takes.

Grenville-Keewatin relations. Miller and Knight believed the Grenville series to rest nonconformably on supposed Keewatin volcanics in southeastern Ontario (6a). The Keewatin age of the volcanics is questionable and the distribution of outcrops of the two series as represented on their map 22e (Lots 12 and 13) is possible only if the volcanics rest nonconformably upon the Granville sediments. Cooke regards the ancient sedimentary series (Nemenjish) of northern Quebec as post-Keewatin and equivalent to the Grenville series. Tolman (2b) has pointed out the uncertainty of the evidence used by Cooke in assigning these sediments to a post-Keewatin position; both he and Moehlman (3b) present evidence that these sediments are at least early Keewatin and the present author found a similar series, in this region, to rest nonconformably below the Keewatin flows (4b). I regard the Grenville as pre-Keewatin but admit the evidence inadequate to give more than an opinion and can conceive that either of two other possibilities may be established in the future.

Grenville-Huronian relations. Correlation of the Grenville series with the Huronian sediments is advocated by T. T. Quirke, whose contributions on the subject merit careful study (7). They might have been included to show the essentials of this correlation. The twofold division of the limestones of southeastern Ontario by Adams (8) and by Miller and Knight (6b) seems logical after careful examination of their maps, but the importance of the discordance is questioned by Wilson (9). If this division is correct, some doubt remains whether the Huronian is the equivalent of the older Grenville series or the younger Hastings group.

Weight of available evidence seems to indicate to me that the Huronian sediments were derived from the southeast (5b), in which event it is extremely improbable that they would become more highly calcareous towards their source—southeastern Ontario—than in the center of the Lower Huronian trough where they accumulated. This is the most significant obstacle to a Grenville-Huronian correlation and, while not insurmountable, it must receive due consideration.

Relative age of the Killarney disturbance and the Keweenawan. The Killarney granite intrudes a series of diabase dikes that cut the Cobalt series. These dikes are usually correlated with the Keweenawan basaltic flows. Probably correlation of the huronite-bearing diabases, which cut the Killarney granite, with the Keweenawan flows might be more nearly correct. On the other side of the argument, lavas and sandstones of Keweenawan age exposed in Batchewana or Batchewanung Bay are more disturbed than average (10); Huronian sediments—Lorrain quartzite—just to the southeast are highly faulted, overturned, and deeply intruded by granite (11). At this locality the regional strike of the Keweenawan is north-south and that of the Huronian is east-west. Absence of granite cutting the Keweenawan and occurrence of granite cutting the Huronian, and discordance of structural trends all within this small area tend to place the Keweenawan as later than the main disturbance. The more disturbed condition of the Keweenawan at Batchewana Bay warns of the possibility that it too may be involved in the Killarneyan movements. These considerations seem to merit a longer reference list than Cooke has given.

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LAUGE KOCH'S EXPLORATIONS IN EAST GREENLAND.

A recent letter from Lauge Koch to one of the associate editors of the Journal contains considerable information that is of general interest to geologists. The Danish East Greenland Exploration party of last summer (1933) numbered 109 men, and was equipped with two steamers, two airplanes, and sixteen motorboats, several of which carried wireless apparatus. Altogether there were twelve wireless stations. There were seven geological parties, with a personnel of thirty-one. The explorations are to be continued next summer. Remarkable progress is being made in the elucidation of the geology of East Greenland, and Koch will describe the geology of the island for the *Geologie der Erde* which is being published by Borntraeger; that of Spitzbergen will be written by Frebold for the same work. Koch is now preparing an article for this Journal on the geosynclines of Greenland and their probable connections in Europe and North America, a synthesis that is much needed both for geology and paleontology.

During the past several summers, much new knowledge has been secured concerning the East Greenland geosyncline and the orogenic histories of the Caledonian and Variscan deformations. In 1932, Koch ascertained the western extent of the Caledonian folding between 70° and 77° N. Lat., and in 1933 he traced it north to Norostrundingen, the easternmost point of Greenland, where the ranges, with formations that are mostly unmetamorphosed but folded and faulted and intruded with granites, continue into the sea toward Spitzbergen. Approximately at the point where the North Greenland and the East Greenland mountain ranges should theoretically meet, Koch believes he saw land from an airplane.

South of 70° N. Lat., the western margin of the Caledonian folding is completely covered by Cenozoic basalt in horizontal beds. From an airplane Koch has traced this basalt sheet into the inland ice to slightly south of 68° N. Lat., where the Caledonian gneiss and granite again appear, though they are more metamorphosed than farther north. It has always been his chief endeavor to determine this Caledonian fully, and toward this end five "schools" were working independently: the parties of Backlund of Finland, Wegemann of Zürich, Wordie and Odell of Cambridge, and Teichert of Germany. "The four former schools agree as to the presence of strong Caledonian movements in East Greenland. I also believe they agree in that it is the western half of the mountain range that is represented there. It is 200-300 kilometers broad, and actually consists of several ranges separated by less strongly moved areas; Liverpool Land and the northern part of Shannon Island belong to the central part of the range, while the whole eastern half has subsided below the surface of the sea. No traces of a borderland have been observed."

"In contrast to the four schools mentioned above, Teichert considers the Caledonian folding in East Greenland to be of a more germanotype character." Teichert has studied especially part of the Eleonore Bay formation, which lies between two mountain ranges and is not strongly deformed, and Koch believes that the deformation is essentially Hercynian and not Caledonian.

The East Greenland coast from 68° to 60° N. Lat. (Cape Farewell) is unfortunately very little known. In the summer of 1932, one of the Danish parties, under Dr. Wager, was at work here in Kangerdlugssuak, and some further knowledge was obtained in the Julianahaab district on the west coast of southern Greenland; and it is on the basis of these unpublished observations that Koch connects the East Greenland geosyncline with the Appalachian one. Supporting this connection are similar Paleozoic faunas in both regions, and the fact that the East Greenland fold mountains can be traced from 82° to at least 70° N. Lat. with the deformation increasing in intensity southward.

Regarding the post-Caledonian orogeny, Koch thinks there is clear evidence of late Devonian diastrophism, though as yet no marked folding is known. Strong early Upper Carboniferous (Asturian) folding and overthrusting, with marked eruptive activity, has been determined. Also, there was slight deformation between the Permian and the Triassic (Pfalzian), and last summer it became evident that the early Cenozoic orogeny was much more intense than had been assumed earlier by Koch; not only had a considerable uplift taken place, but granitic intrusions and local folding as well.

Finally, Koch saw from an airplane that the entire peninsula bounded by the southern ramifications of Scoresby Sound in 70° N. Lat. and Kangerdlugssuak in 68° N. Lat., and to about 32° W. Long. is covered by basalt having a thickness of something like 2000 meters, and that the basalt overlies the gneiss even in the westernmost nunataks, though here it thins out because of the rising of the gneiss basement. North of Kangerdlugssuak to nearly 70° N. Lat. there occur, some distance from the coast, four large mountain massifs with a length of about 120 kilometers and a width of 30-40; here the thick basalt formation has been raised some 2000 meters and lies on a basement of gneiss and granite, the mountains attaining a height of 4000-4500 meters. No doubt this is a very young uplift, and it will be the subject of further study next summer.

Large collections of fossils were brought back, including many thousands of specimens of Upper Devonian stegocephalians, placoderms, lung-fishes, crossopterygians, etc.; between 3000 and 4000 beautiful fishes and many stegocephalians from the lowermost Triassic; large numbers of ganoids and sharks from the earliest Permian (Schwagerina zone); and of invertebrates many ammonites of Triassic and Jurassic (Portlandian) ages. Gold, silver, lead, zinc, molupden, and other minerals were also found.

The editors of the Journal congratulate Doctor Koch on his marked success, and wish him good luck in his further undertakings in Greenland. [CHARLES SCHUCHERT.]

SCIENTIFIC INTELLIGENCE.

CHEMISTRY AND PHYSICS.

Introduction to Physical Chemistry; by ALEXANDER FINDLAY. Pp. v, 478 pp.,. 124 figs. New York, 1933 (Longmans, Green and Co., $3.00).—Professor Findlay has consistently employed the historical approach to each topic in this excellent text, a method which seems peculiarly essential for the first course in such a rapidly evolving subject. The experimental basis for the phenomena discussed, is emphasized very appropriately. Many simple illustrative experiments are suggested and there are numerous diagrams of apparatus which clarify the discussion.

In addition to the usual subjects there are separate chapters on catalysis, critical phenomena in general, the second law of thermodynamics, photochemistry and adsorption. The phase rule is brought forward in considering many aspects of heterogeneous equilibria. This particular method is a very useful one in their interpretation. In the appendix there are more than one hundred and fifty numerical examples with answers. The book is an intensely practical one and should be of great value as a basis for a modern university course. JOHN E. VANCE.

The Kinetics of Reactions in Solution; by E. A. MOELWYN-HUGHES. Pp. vi, 313. New York, 1933 (Oxford University Press, $5.00; Oxford, At the Clarendon Press).—After several articles on the subject during the recent past, Dr. Moelwyn-Hughes has written this book with the purpose of demonstrating that the kinetic theory of gases may with reason be applied generally in the interpretation of reaction rates whether in solution or in the gas phase.

A general discussion of the collision theory and of the equation of Arrhenius is first presented and is followed by a survey of unimolecular, bimolecular, ionic, catalyzed and heterogeneous reactions and of equilibria in solution. Scores of reactions under these classifications are cited and data pertaining to them compared with the predictions of the simple collision theory.

That a collision must precede a reaction between molecules is a view held by all, but probably relatively few are willing to accede to a complete use of the kinetic gas theory in solutions since the two media are commonly looked upon as being radically different. The close agreement between calculated and observed results in many cases, however, can hardly be considered the result of chance. Whatever the final solution of the problem, and Dr. Moelwyn-Hughes makes no claim for the absolute nature of this particular one, this interesting and readable treatise will be of great value as a stimulant in a field where no previous attempt at correlation of rate constants has met with the slightest permanent success.

JOHN E. VANCE.

The Artificial Transmutation of the Elements; by Lord RUTHERFORD. Oxford University Press, 12 pp., 1933.—Under the above title was delivered the thirty-fifth Robert Boyle Lecture before the Oxford University Junior Scientific Club, June 2, 1933, and the work on the disintegration of atoms by artificial means was reviewed by the lecturer in the essentially fundamental points. Lord Rutherford was the first scientist to obtain the disintegration of an atom of an ordinary element when, in 1919, he bombarded a nitrogen atom by α-particles of radium C′ and showed that a proton, i.e., hydrogen nucleus, was emitted when the hit by the α-particle was favorable. In his laboratory, Blackett had shown, by studying the bombardment of nitrogen by the fast α-particles of thorium C′ that the nitrogen nucleus "absorbed" the α-particle and emitted a proton leaving the residual nucleus to become the isotope of oxygen of mass 17.

These two fundamental researches form the basis of present-day investigations in the field of disintegration of elements. Rutherford and Chadwick and others have found definite evidence of the emission of protons by twelve elements when bombarded by α-particles.

Another important contribution was made by Bothe in his work bombarding beryllium and boron atoms by polonium α-particles. He discovered a penetrating radiation emitted by the bombarded beryllium. Part of this penetrating radiation was shown by Chadwick to be an electrically neutral particle of mass 1 which he called the neutron. The beryllium, mass 9, and the α-particle form an atom of carbon, mass 12, and a neutron, which is emitted. In the hands of Feather it was shown that neutrons from beryllium would disintegrate both nitrogen and oxygen, whereas oxygen was not disintegrated by α-particles.

The next step in the method of attack is the development of methods of obtaining high-speed positive ions and the use of these to bombard the atoms to be disintegrated. The obvious necessity seemed to be the development of high voltage apparatus to speed up the ions. The first work of this kind was done in the Cavendish laboratory by Cockroft and Walton, who speeded up positive hydrogen ions (protons) and were successful in disintegrating lithium. They showed that the lithium nucleus and the hydrogen nucleus form two helium nuclei, which as such form an unstable product. This breaks up and the two α-particles are emitted. Tracks of these two α-particles were obtained in a Wilson Cloud chamber.

Other methods of obtaining high speed positive ions have been developed and some of these are truly ingenious devices, as, for example, the method of multiple acceleration of Professor E. O. Lawrence of the University of California. It is obvious that all ingenuity is summoned to bring about ways of disrupting the nuclei of atoms. The results of such investigations should show us the constitution of the nuclei of atoms and give us information about the tremendous forces in these nuclei.

ALOIS F. KOVARIK.

GEOLOGY AND GEOGRAPHY.

Mémoires du Service de la Carte Géologique d'Alsace et de Lorraine. Université de Strasbourg, 1 rue Blessig. Emm. de Margerie, Director. No. 1. *La Géologie des Puits des Mines de Potasse de la Haute Alsace*; by W. WAGNER.—The importance of potash in the arts and the comparative rarity of its compounds in nature give a special interest to this detailed discussion of its occurrence in Upper Alsace. The text of the work (447 pages; 41 figures) describes in full detail the many Concessions, each with its distinctive name and with a presentation of the definite geological facts. The results given, obtained through very careful observation and study, are presented graphically in another volume giving the Atlas of forty-two plates.

The first twelve plates are geographic. They show the position of each Concession, duly named and outlined. The location of each, with reference to the prominent towns in or near the area is given, with also the railroad lines and the chief roads. Plate 1 thus locates the two Concessions named Joseph and Else with which the adjacent Concessions are given in part. Appropriate signs show the position of the borings which yield potash, and also those with rock salt. A continuous red line gives the limit of the lower bed of potash, while the dotted red line locates the upper bed.

Plates 13 to 42 give vertical sections of each of the pits. Nos. 13 to 23 are confined to the lower portion which contains the potash (sylvite). These differ widely, but there is usually an upper bed separated from the lower by layers of rock salt, clay and anhydrite, and a special layer containing distorted crystals of halite. Thus for Else there is the single upper bed of potash, while twenty meters below there are three potash beds close together.

The remaining plates, Nos. 24 to 42, give complete sections in color for the entire depth from the Quaternary to the potash layers at the bottom. For Else this depth is 512 meters with about 270 meters above sea level and 240 meters below. Another pit (plate 34) has an extreme depth of over 1040 meters, with only 218 meters down to sea-level, and about 800 meters from there to the two beds of potash, 20 meters apart. The different geological zones through which the borings have gone are distinguished by the color given to them.

Geological Survey of Great Britain.—Summary of Progress for the year 1932. Part II, pp. 142; 10 pls., 32 figs. (H. M. Stationery Office, price 3s. net, postage extra).—Sir John S. Flett opens this number with a discussion of the complex geology of the Meneage in Cornwall. Of special interest is the "crush zone," a belt of broken rocks six miles in length, extending from the east coast to the Lizard road. Three papers follow on the geology of the Kent coalfield. These include the sequence and structure, by H. G. Dines; the fossil Flora, by R. Crookall; the Fauna, by C. J. Stubblefield. Other papers include one on the Lower Ordovician Graptolite Faunas, by Gertrude L. Elles, and another on the Fauna of the Paleozoic rocks of the Little Missenden boring, S. H. Straw and Sir A. S. Woodward.

The Geology of Texas. Volume I, Stratigraphy; by E. H. SELLARDS, W. S. ADKINS, and F. B. PLUMMER. Univ. Texas Bull. No. 3232, 1932. Pp. 1007; 10 pls., 54 figs. Geol. map in pocket. 1933.—This compendium of the stratigraphic geology of the largest state in the American Union, with an area of over 262,000 square miles, describes the essential formations and traces many of them underground through the tens of thousands of oil wells all over the state. The new geological map, on the scale of 1:2,000,000, is in eleven colors, but, by means of letter symbols and boundary lines, differentiates fifty stratigraphic units and four igneous ones. The book will be most useful, not only to the geologists of Texas, but to all teachers of geology. The second volume, in preparation, will discuss the structure and the economic resources.

Part I, by Sellards, treats of the Pre-Cambrian (pp. 27-54) and Paleozoic stratigraphy (pp. 55-238); Part II, by Adkins, describes the Mesozoic formations (pp. 239-518); and Part III, by Plummer, is concerned with the Cenozoic (pp. 519-818). The bibliography and subject index, prepared by Sellards, occupies pages 819 to 965, and is followed by a detailed index. There are nine plates of guide fossils, but these are too few to do the subject justice.

The periods best developed in Texas are the Pennsylvanian, Permian, Cretaceous, and those of the Cenozoic; the Upper Cambrian, Ordovician, Silurian, Devonian, and Mississippian are but sparingly represented, the late Triassic is present in continental beds, and the Jurassic is known in but one county, adjoining the Mexican border. The greatest natural resources of the state are in the Cenozoic deposits, which have tremendous amounts of salt, petroleum, lignite, water, and sulphur.

The Texas Bureau of Economic Geology deserves much commendation for this fine addition to the growing list of comprehensive state reports. C. S.

Glossary and Correlation Charts of North American Tertiary Mammal-bearing Formations; by GEORGE G. SIMPSON. Bull. Amer. Mus. Nat. Hist., 67, Art. III, pp. 79-121, 1933.—This important work on correlation, with a glossary of the continental deposits of North America, should be on the desk of all stratigraphers, since it brings out the status of over 130 formations or mammal horizons. Of these names 45 are of little or no use. The remaining 90 units are located on a geographic map and 65 of them appear in the seven correlation charts.

The Mesozoic era is ended with the Lance and Hell Creek formations, and the first epoch in the Cenozoic is the Paleocene, which begins with the Puerco and closes with the Clark Fork. Above the Paleocene the guiding fossils are the horses, which are of major significance in bounding the mammal horizons. The article is a fine report of progress, and makes clear what is known, what is debatable, and what needs further field discoveries. The author is to be congratulated on this very helpful summary.

C. S.

Historical Geology; by RAYMOND C. MOORE. Pp. xiii, 673; 413 figs. New York, 1933 (McGraw-Hill Book Co., $4.00).—This attractive textbook of historical geology has several unique features. The physical history of the Earth is discussed in chronologic order, with the use of era and period names generally employed by geologists. Life development, however, is not taken up period by period; it is treated in a few chapters, each covering a long span of time. Thus, after devoting a chapter to each of the first three periods in the Paleozoic era, the author gives a unit discussion of the "life of early Paleozoic time." The same procedure is followed for late Paleozoic time, for the Mesozoic era, and for the Cenozoic era. From his teaching experience, the author believes that this device, affording greater continuity of treatment, is superior to the more disjointed period-by-period discussions of life given in most other geologic textbooks.

Nearly all of the illustrations are selected with good judgment and are reproduced well in the printing. Numerous excellent block diagrams drawn by the author are included. Some of the blocks and cross-sections have the fault that no indication of compass directions is given. Most of the plates showing fossil forms have the background in solid black, which affords excellent contrast. Another commendable feature is the printing of fossil names directly on the plates; the less convenient scheme generally used is to print the names in a legend below each plate, with guide numbers.

Paleogeographic maps are not favored by Professor Moore, "because such maps are for the most part highly subjective, the data used in constructing them are generally not evident, and the sometimes very small areas of reasonable control are not differentiated from the uncontrolled areas." The book employs numerous maps showing outcrop areas of the several systems, with a pattern to show the inferred areas of original distribution of formations. Obviously, these maps also are open to criticism. The basis for the inferred areas is in large part not evident, since the small-scale maps cannot show numerous small but significant outcrops, and the highly important data from wells and similar sources cannot be indicated. If the student is given the impression that the outcrop areas shown are the chief basis of inference, he may develop a skepticism as legitimate as that provoked by reconstruction of a complete vertebrate animal with only a single tooth as a guide. All teaching devices require considerable supplementary explanation, and most teachers of geology find that both paleogeographic and outcrop maps are valuable if they are used judiciously.

Professor Moore's book is scholarly, well organized for teaching, and attractive in form. It will find a useful place in the teaching of historical geology. CHESTER R. LONGWELL.

Michigan Papers in Geography.—This is the third volume of papers on Geography, mostly by members of the University of Michigan. They are reprinted from "Papers of the Michigan Academy of Science, Arts and Letters" and give substantial evidence of the scholarly position that a long neglected science has won in a state university where but a few years ago it was unrepresented. Two of the most noteworthy papers are: Landforms of Japan, by R. B. Hall and A. Watanabe; and Greenland, the advances of a decade (1921-31), by W. H. Hobbs (this Journal, July, 1933, p. 85). W. M. D.

The Tukang-besi Islands.—Escher showed in 1920 that the Tukang-besi islands, southeast of Celebes, are arranged in four rows; the first and third rows being atolls, the second and fourth bearing elevated reefs. They have lately been studied in detail by Koenen (Proc. K. Akad. Wetenschappen, Amst., 36, 1933), who concludes that their region is unstable, that low-level abrasion in the Glacial period was inoperative, and that reef upgrowth to a maximum measure of 1000 meters has taken place during subsidence, followed by upheaval in the second and fourth rows. This essay is illustrated by an excellent block diagram, showing the form of the sea floor from which the islands rise. W. M. D.

Geographic Surveys; by VERNON C. FINCH and ROBERT S. PLATT. Geographic Society of Chicago. Bulletin No. 9, 1933. Pp. xiii, 75, with plates and figures (50 cents).—Part I of this volume gives an instructive discussion of the general subject of Geographic Surveying, by V. C. Finch (pp. 3-11). Part II, by same author, is devoted to Montfort, Wisconsin, and gives an interesting study of the land surface in the southwestern part of the State. The eighteen half-tones show the varied character of the scenery. The nine large plates, which follow, illustrate in detail the varied land surface with its utilization for different crops, the woodland and permanent grass.

Part III, by Robert S. Platt, presents a detailed study of a small pueble (4 square miles), Magdalena Atlipac, wisely selected as typical of the Central Plateau of the Valley of Mexico. The types of land noted include the sloping mountain side, relatively dry and yielding inferior crops; also the cultivated slope, an area of fertile sandy loam, well watered and yielding good crops of various kinds. The half-tones illustrate these as well as some aspects of the life of the people. A fundamental distinction exists between this Central Plateau and the outlying regions. These, however, may be important in what they yield, as the mineral deposits in mountain regions and the oil fields of the Gulf Coast. Further, it is to be noted that viewing Mexico as a whole, many miles of desert separate the real Mexico and the United States.

BOTANY.

Pflanzenthermodyncmik; by KURT STERN. Pp. xi, 412. Berlin, 1933 (Julius Springer, RM. 32, bound 33 RM.).—This monograph on the thermodynamics of plants is divided into two sections. The first deals with the fundamental conceptions of thermodynamics, and in detail with the phase rule, chemical energy, electrical energy, light energy and surface energy. In the second section applications of thermodynamics to the processes in plants are treated. The thermodynamics of the chemical reactions, electrical phenomena, carbon dioxide assimilation and surface phenomena in plants are considered with a closing chapter dealing with the general energy relations of the physiological work of plants.

This treatise brings together in convenient form the literature dealing with the energy relations of plant processes and plant growth in general. While the mathematical treatment of the subject matter will appeal primarily to the specialists in this field of plant research, the work as a whole should also serve as an excellent source of reference to the plant physiologist with occasional questions or problems in thermodynamics. CARL G. DEUBER.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

El Libro del Saber; RAMÓN SOTO FÉRNÁNDEZ. Pp. 149; 27 figs., fig. 1, Saturn with its ring as frontispiece. Toledo, 1933 (Talleres Tipograficos . . . .).—According to the author's preface, the first part of this book discloses the key of the Mythologies, which is that "the Earth has had a Ring just as Saturn has one now. The Mythologies do not deal with anything more than the history of this Ring." In addition, this first part contains a summary of choice specimens of the literature of antiquity. The second part concerns itself with Creation and the fundamental law of the Universe, which is as follows: All structures of the Universe, molecules, stars and systems were formed by the action of concurrent radiations which sustain them and determine their character. The third part treats of molecular physics and aims to show that all properties and qualities of matter are due to the aforesaid law, there being, therefore, only one law in the Universe. The fourth part professes to demonstrate that all phenomena which to-day are termed psychical, are physical. The fifth part, finally, announces a new Society based upon a new economic system.

One of the characteristic features of the new system here proposed, is that while a person's property is to be respected during his life-time, upon his death it is attached by the 'Council of Elders' of his District, and by them is apportioned to those considered to have the best claims to it.

The book closes with a chapter advocating the adoption of a simplified form of Spanish, the author's mother-tongue, as a "rational," in other words, international language. Needless to say, this scheme can hardly expect more general acceptance than its already numerous predecessors. For one thing, French, and in recent times more frequently English, have to all intents and purposes satisfactorily served as mediums of international intercourse, and only a very limited number of people care to acquire, without especial need, a practical command of a foreign idiom.

While in principle the highest rank may properly be accorded to the language capable of expressing the greatest amount of meaning with the simplest mechanism, it must be borne in mind that a given simplification in linguistic structure does not make a language equally easy for people of more or less widely different habits of speech. As has been rightly observed, languages vary very much in easiness even to native speakers. And the supposition that a so-called international idiom, however skilfully devised, will for any length of time retain everywhere the uniformity of pronunciation essential to the achievement of its purpose reminds one of the notice said to be posted in a Peking hotel: "English spoken, American understood." H. R. LANG.

The *Eugenio Rignano Prize given by Scientia.*—In the latter part of 1932, the Editor of Scientia offered to the public a prize of 10,000 Italian lire for the best essay on "The Evolution of the Concept of Time."

This prize is named in honor of Dr. Eugenio Rignano, who was the Editor of Scientia for many years, until the end of October, 1930. Later, the Committee announced that, in response to their call, 35 important works were received; of these 33 satisfied the conditions named.

The Jury has now reached the decision that the prize be divided equally between M. Sigismund Zawirski, professor in the University of Poznán, Poland; and M. Giovanni Giorgi, professor in the University of Palermo.

Philosophy of Science.[1] Volume I, No. 1, pp. 131. January, 1934.—The editorial board of this new Quarterly includes, as Editor, William M. Malisoff, with twelve Associates and an Advisory Board of forty-two. It is the organ of the Philosophy of Science Association, defined as "the organized expression of the will of a fairly large body of intellectually competent individuals whose basic interest is in both science and philosophy, and particularly in their union." It thus fills a new and interesting place among the periodicals appealing to scientists.

The following are among the articles of the first number now distributed: Character of philosophic problems, R. Carnap; Finite or infinite, E. T. Bell; Foundations of the theory of probabilities, D. J. Struik; an examination of Quantum theories, W. M. Malisoff; Quantum mechanics as a basis for philosophy, J. B. S. Haldane.

Philosophische Hefte. Verlag der Maximilian Beck, Praha-Dejvioe. September 13, 1933.—This Journal, now in its fourth year, has recently issued Heft 1/2, pp. 94 (RM. 3).—This number contains the following articles: Versuch einer Kultur-genealogie, Maximilian Beck, pp. 1-60; Die Bedeutung der Ganzheitsbetrachtung in der heutigen Biologie, H. André, pp. 61-75; Das objektive Rangordnungsprinzip in der Biologie, Armin Müller, pp. 76-85. The closing pages (86-94) are given to book reviews.

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[1] Published quarterly by the Williams and Wilkins Co., Baltimore. Net price, $5.00 (Postal union); $5.50 (outside).

OBITUARIES.

BARON FRANCIS NOPCSA, the eminent vertebrate paleontologist, died on April 25, 1933, a few days before his fifty-sixth birthday. Hungarian by birth, his student work was with Professor Eduard Suess of Vienna. Subsequently, he devoted himself with important results to the study of reptilian remains in the field and the Museums. A long series of his papers on fossil reptiles was followed by the important volume "Die Familien der Reptilien" (1923). The factors affecting the distribution of fossil reptiles and Stegocephalians he also discussed at length. He did much field work, especially in Albania, with the large volume "Geographie und Geologie in Nordalbaniens" (1929) as the result. A list of his many papers is given by Dr. K. Lambrecht in his obituary notice (Paleontologische Zeitschrift, vol. 15, pp. 201-221).

DR. AUGUSTUS TROWBRIDGE, professor of physics in Princeton University from 1906, and dean of the Graduate School from 1928, until his retirement in 1933, died suddenly at Taormina, Sicily, on March 14 at the age of sixty-four. He was a distinguished physicist as well as an able administrator.

DR. ERWIN BAUR, professor of botany at Berlin and prominent in the research of plant genetics, died on December 2 at the age of fifty-eight.

DR. FRITZ HABER, professor of physical chemistry in the University of Berlin, died on February 1 at the age of sixty-five.

DR. WILLIAM EDWARD GIBBS, professor of chemical engineering at the University College, London, died on January 18 at the age of forty-four.

MRS. NATHANIEL LORD BRITTON, honorary curator of mosses in the New York Botanical Garden, died on February 26 at the age of seventy-six. Her husband was the director-in-chief of the New York Botanical Garden from 1896-1929.

DR. ROBERT HENRY WOLCOTT, professor of zoology in the University of Nebraska, died on January 23 at the age of sixty-five.

PUBLICATIONS RECENTLY RECEIVED.

Carnegie Institution of Washington, News Service Bulletin. Vol. III, No. 12. Ions in the Air.

Our Primitive Contemporaries; George P. Murdock. New York, 1934 (The Macmillan Co., $3.60).

The Carnegie Foundation for the Advancement of Teaching. Twenty-eighth Annual Report of the President and of the Treasurer. 1933 (522 Fifth Ave., New York).

Vorträge gehalten zum 9. Deutschen Physiker-und Mathematikertag in Würzburg 1933. Leipzig, 1933 (Johann A. Barth, RM. 6).

Contributions to Palaeontology. Marine Mammals; by Earl L. Packard, Remington Kellogg, and Ernst Huber. 1934 (Carnegie Institution of Washington).

Carnegie Institution of Washington. Year Book No. 32, 1933.

The Deformation of the Earth's Crust; by Walter H. Bucher. Princeton, 1933 (Princeton University Press, $5.00).

Papers from the Tortugas Laboratory of Carnegie Institution of Washington. Vol. XXVIII, No. 435. 1934.

An Introduction to the Teaching of Science; by Elliot R. Downing. Chicago, 1934 (University of Chicago Press, $2.00).

Reality and Illusion; by Richard Rothschild. New York, 1934 (Harcourt, Brace and Co.).

Streifzüge durch die Unwelten von Tieren und Menschen; von J. Baron Uexküll and G. Kriszat. Berlin, 1934 (Julius Springer, RM. 4.80).

Field Museum News. March, 1934. The Beginning of Life, A Billion Years Ago, is Subject of Mural.

The Clay Resources of Indiana; by George I. Whitlatch. Pub. No. 123. Indianapolis, 1933 (The Department of Conservation State of Indiana).

Geology of Puerto Rico; Howard A. Meyerhoff. (The University of Puerto Rico, 1933.)

Principes de Géologie; P. Fourmarier. Paris, 1933 (Masson et Cie, 120 Boulevard Saint-Germain, 250 Fr.).

Bulletin du Service de la Carte Géologique D'Alsace et de Lorraine. Tome 2-Fascicule 1, avec 8 Planches. Strasbourg, 1933.

The World Around Us; by Samuel R. Powers, Elsie F. Neuner, and Herbert B. Bruner. Boston, 1934 (Ginn and Co., $1.20).

Colour Science; by Wilhelm Ostwald. Part I. Colour Theory and Colour Standardisation. Part II. Applied Colour Science. London, 1934 (Winsor & Newton, 38 Rathbone Pl., Pt. I, $5.00, Pt. II, $3.75).

Bumblebees and Their Ways; by Otto E. Plath. New York, 1934 (Macmillan Co., $4.00).

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QUANTITATIVE METHODS OF MICRO-ANALYSIS WITH SPECIAL REFERENCE TO THE GORDONIA URANINITE.

FRIEDRICH HECHT.

A. INTRODUCTION.

In the following pages a description will first be given of the various appliances and pieces of apparatus which are necessary for the carrying out of analyses of minerals by micro methods[1]; this is followed by a detailed account of the procedure adopted in the analysis of specimens of Gordonia uraninite, collected by the late Dr. P. Wagner for Professor Arthur Holmes, at whose suggestion this work has been carried out.

B. GENERAL DESCRIPTION OF APPARATUS AND METHODS OF PROCEDURE.[2]

In all my work crucibles and filtersticks (for inverted filtration by Emich's method[3]) made of platinum or porcelain were used. The platinum vessels and filtersticks (which latter were fitted with a Munro filter disc) were manufactured by Heraeus at Hanau, Germany, the porcelain ones by the Berlin State Porcelain Manufactory. The porcelain crucibles had an external diameter of 33 mm. at the top, and 19 mm. at the bottom; their height was 43 mm., and their capacity 25 cc. The measurements of the platinum crucibles were: upper diameter 28 mm., lower diameter 17 mm., height 40 mm., capacity 20 cc. The area of the bottom was fairly small, so as to permit of the

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[1] Cf. Hecht, F., Mikrochemie, 10, 45 (Microanalysis of Morogoro pitchblende), 1931; Mikrochemie, 12, 193 (Microanalysis of Ceylon Thorianites), 1932; Hecht, F., and Reich-Rohrwig, W., Mikrochemie, 12, 281 (Microanalysis of pitchblendes), 1933; Hecht, F., Mitt. Inst. Ra-Forschung Wien, Nr. 281, 1931.

[2] A description of all apparatus mentioned in the present paper has been previously published by W. Reich-Rohrwig and the author in Mikrochemie 12, (l. c.) 1933.

[3] Emich, F., and Schneider, F., Microchemical Laboratory Manual, Wiley, N. Y., 1932.

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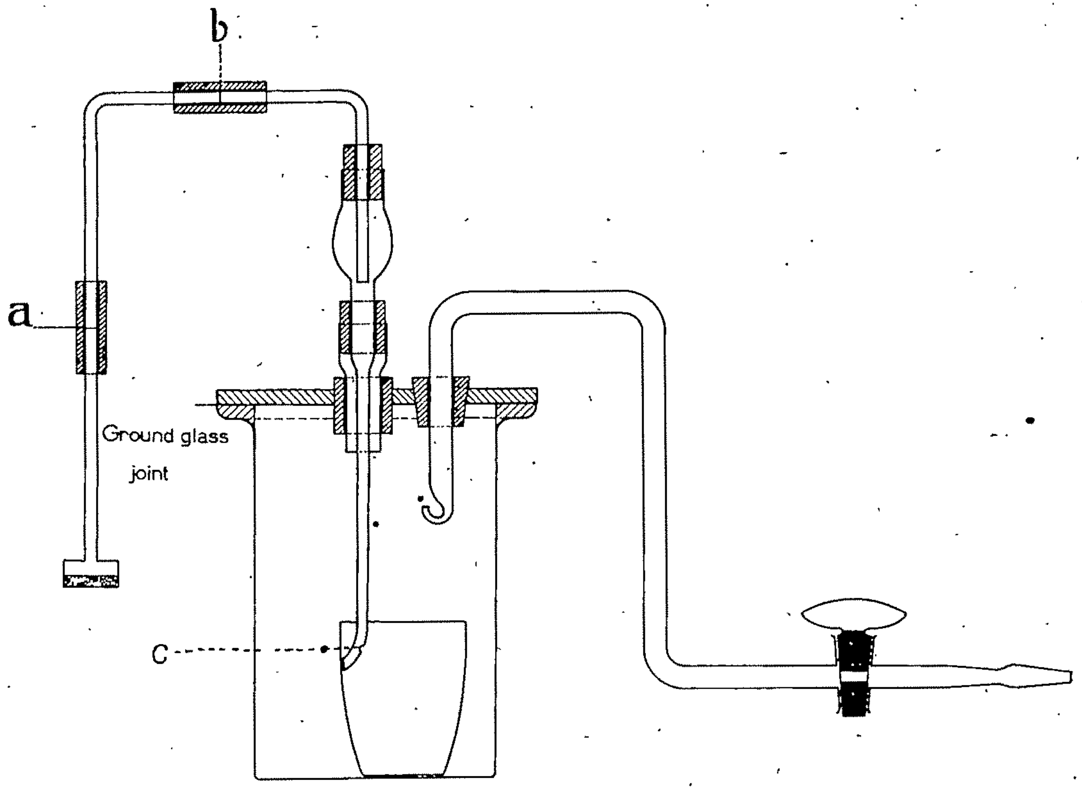

Fig. 1

use of small quantities of potassium pyrosulphate for the fusion of insoluble substances. Fig. 1 depicts a filterstick (left-hand side, below *a*), also the apparatus necessary for filtering a solution through the stick into another crucible. The terminal capillary tube has a small hole at *c*, close to its lower end, in order to prevent loss of solution through the formation and bursting of air-bubbles. This apparatus was devised by R. Dworzak and W. Reich-Rohrwig after the pattern of a macro apparatus of Professor A. Franke, which was employed for filtering a solution through a Gooch crucible directly into a beaker; it is an improved model of J. Donau's filter bell jar.[4] The introduction of hydrogen sulphide is effected by means of a curved clock glass with a capillary tube fused through it (see Fig. 2). The clock glass can be weighted if necessary with pieces of metal or with water. If the lower part of the capillary tube is made shorter and bent at an angle, the apparatus can be used to pass a stream of HCl gas over carbonate solutions in order to neutralize them. In order to prevent loss due to effervescence the crucibles are covered with a hollow glass ball having a projection on its lower side which serves to return the condensed liquid to the crucible (see Fig. 3).[5] The ball is filled with water to act as a condenser.

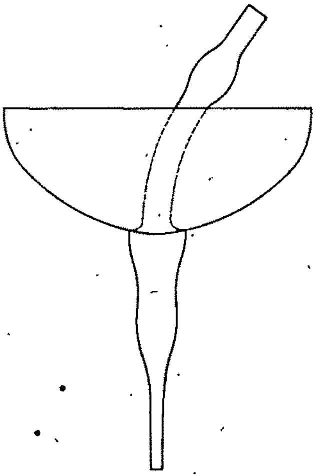

Fig. 2

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[4] Emich, F., and Schneider, F., l. c.
[5] Ibid.

As a water bath, the following apparatus (Fig. 4)[6] proved quite satisfactory. A Jena glass vessel containing distilled water was heated by means of an electric hot plate. The upper portion of the apparatus (which fits on to the lower portion by means of a ground glass joint) has two openings on which dishes or crucibles can be placed. Inverted funnels clamped above these openings and connected with a filter pump enable the vapours from the solutions evaporated in the dishes or crucibles to be drawn off. The distilled water in the lower portion of the apparatus is condensed and returned by the reflux condenser A. Openings not in use can be closed by a glass cover (*a*, Fig. 4). Interchangeable insets (*b*, Fig. 4), permit of the employment of crucibles and dishes of different sizes. The apparatus described prevents contamination of the liquids being evaporated by the flame gases, dust from the air, or metallic particles derived from the usual forms of metal water baths, and the exterior of the dishes and crucibles always remains perfectly clean. In addition, as the vapours of the liquids evaporating are drawn off by a pump, the micro balance may be set up in the same room in which the chemical work is carried out, and where the water bath is in use, this arrangement effecting a considerable saving of time.

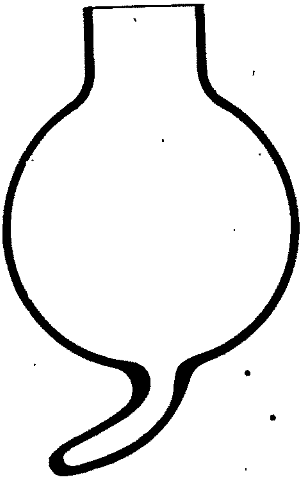

Fig. 3

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[6] Reich-Rohrwig, W., Mikrochemie, 12, 189, 1932.

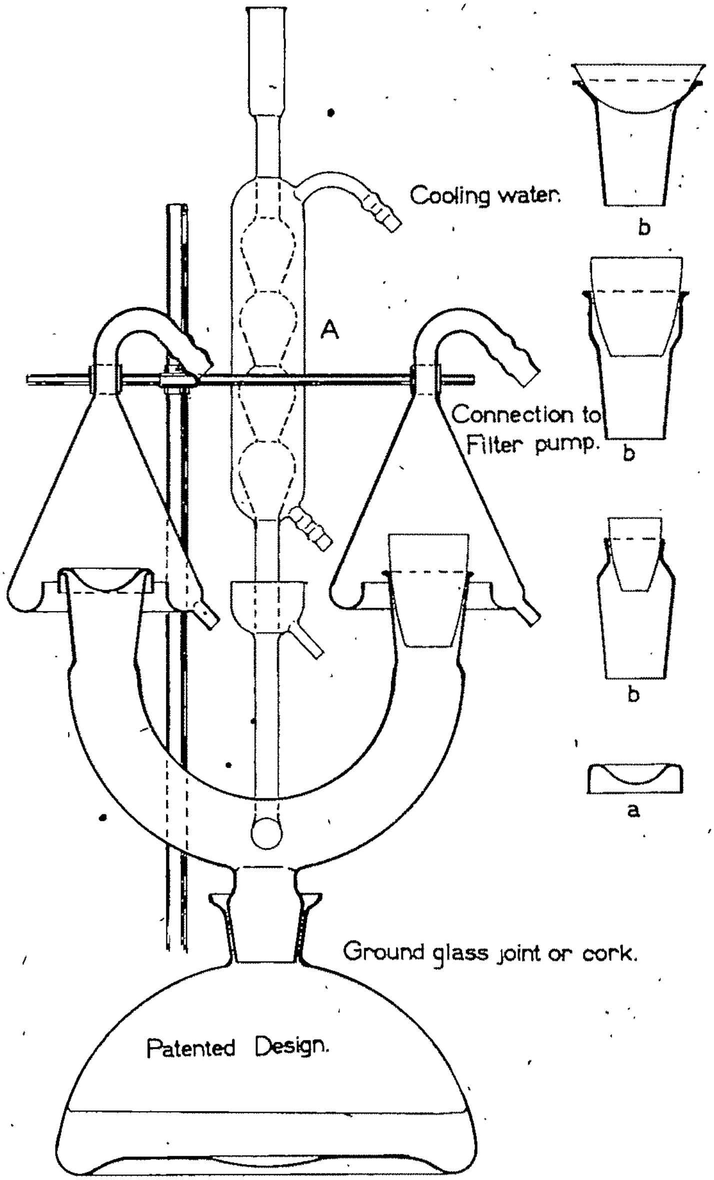
Cooling water.
b
A
Connection to
Filter pump.
b
b
a
Ground glass joint or cork.
Patented Design.

Fig. 4

Precipitates which do not require ignition can be precipitated in the micro filterbeaker made by Schott u. Gen., Jena, Germany, of Jena glass.[7] This beaker (Fig. 5) is a vessel in which both precipitation and filtration can be carried out, the latter operation being effected by means of a sintered glass disc fixed in a projecting side tube. After filtration and washing have been completed, the beaker and contents are dried at a definite temperature and weighed. In Fig. 5 is shown the transference of a solution to a micro filterbeaker through a porcelain filterstick.

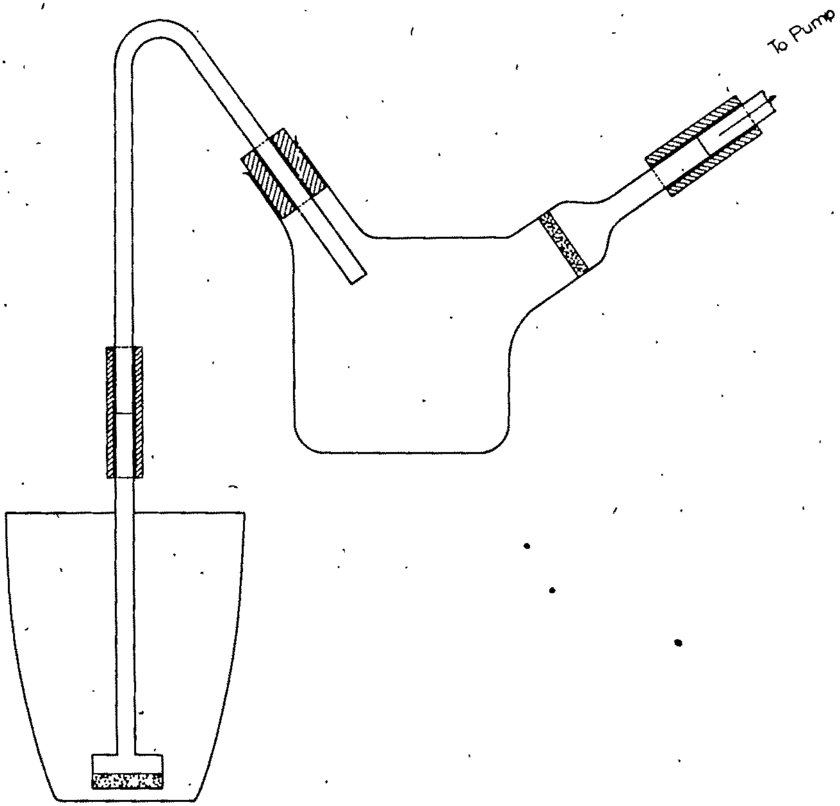

Fig. 5

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[7] Schwarz-Bergkampf, E., Zeitschr. analyt. Chem., **69**, 336, 1926.

For adding drops of reagents small capillary pipettes were used, which were kept in a glass holder (Fig. 6).

The upper portions of the wash bottles and the covers of the weighing bottles fitted over the lower portions with ground glass joints, in order to prevent contamination by abraded glass powder.

The platinum crucibles and filtersticks were cleaned by fusion with potassium pyrosulphate, followed by solution of the melt in nitric or hydrochloric acid, and washing with water under suction. The "insoluble residue" was removed by fusing it with sodium carbonate. The porcelain and glass vessels and filtersticks were cleaned with chromic-sulphuric acid.

C. ANALYTICAL PROCEDURE.

A platinum crucible and a platinum filterstick were wiped on the outside with a moist chamois leather, and then heated for 5 minutes to about 1000° in an electric oven, after which they were cooled to room temperature upon a copper block placed under a glass bell jar. After 5 minutes the crucible and filterstick (which were handled throughout with platinum-tipped forceps—never with the fingers) were placed inside the open case of the micro balance, and weighed after standing there for 20 minutes. The filterstick was then removed from the crucible in which it had been placed during the weighing, and placed beside it on the balance pan. About 30 mg. of the mineral were weighed into the crucible, 15 drops of 1:1 nitric acid added by means of a capillary pipette (1 drop = 0.05 cc.), the crucible covered with the hollow glass ball previously described, and the whole heated on the water bath for 30 minutes. After rinsing back the liquid condensed on the lower part of the glass ball, the solution was carefully sucked through the platinum filterstick into a second platinum crucible which had been previously weighed together with a platinum filterstick. The small insoluble residue was washed three times with 1 cc. of hot water containing a little nitric acid. (Filtrate F_1, residue R.) The rinsing of the crucible with the above small quantities of wash liquid is accomplished by inclining and rotating it. The stem of the filterstick and the outer side of the crucible are then wiped with a moist chamois leather, and the two are then dried in an oven at 110°, and then heated in the electric oven for 5 minutes at 1000°. After cooling

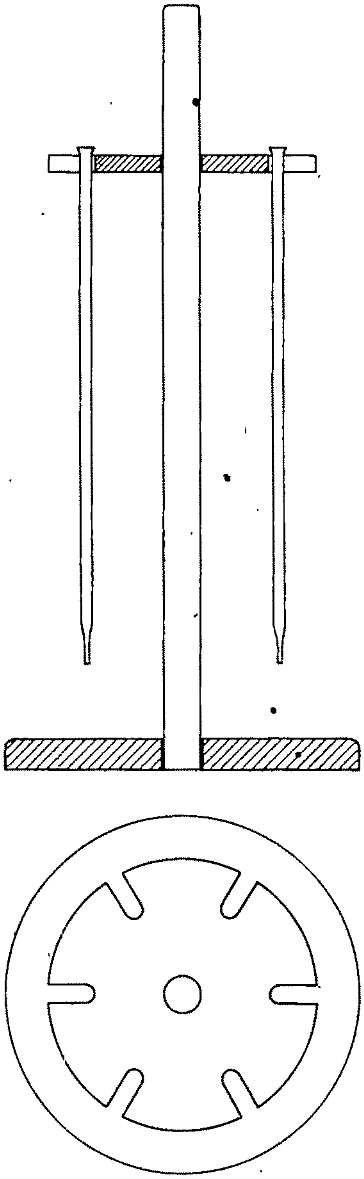

Fig. 6

on the copper block, and standing in the balance case for 20 minutes, as previously described, the crucible and filterstick are weighed. The difference between this weight and the previous weight of the empty crucible and filterstick gives the insoluble residue. Ten drops of hydrofluoric acid (previously distilled in platinum) and 1 drop of sulphuric acid were added, the HF evaporated off on the water bath and the sulphuric acid removed by heating on an electric hot plate covered with an inverted funnel through which the fumes were sucked away by means of a pump. On reweighing the crucible and filterstick the amount of silica present in the insoluble residue is given by the difference between this and the previous weighing. Filtrate F_1 was evaporated to dryness on the water bath, a few drops of nitric acid added, and the whole again evaporated. A little more nitric acid was then added, and the evaporation to dryness repeated. The residue was taken up with 2 cc. of hot 10% nitric acid, and the solution filtered into a porcelain crucible through the platinum filter. The residual silica was washed twice with hot 10% nitric acid, and then once with hot water, after which the crucible and filterstick were ignited and weighed as before. In the case of the analyses dealt with in this paper the amount of silica obtained here was so small as to render a treatment with HF and sulphuric acid unnecessary. The filtrate, F_2, was evaporated to dryness, and the residue treated repeatedly with a few drops of HCl and water followed by evaporation, care being taken that no marked evolution of gas took place during the process. The dry residue was finally taken up with 3 drops of HCl, and the solution diluted to 6 cc. Hydrogen sulphide was then passed into the solution for 30 minutes, using the apparatus depicted in Fig. 2 for the purpose. The precipitate of sulphides was filtered through a porcelain micro filterstick, the filtrate being collected in a porcelain crucible (F_3). The filterstick with the adhering precipitate was treated in the crucible with a few drops of ammonium polysulphide. After heating for a few minutes on the water bath, the residual lead sulphide was filtered through the same filterstick, the filtrate being received in a second porcelain crucible (F_4). The residue R_2 was heated with 1 cc. of dilute nitric acid (1:3), then 0.5 cc. of hot concentrated nitric acid was added, and the solution filtered through the porcelain filterstick into a previously weighed platinum crucible, followed by three washings, using 0.5 cc. of hot 1:1 nitric acid each time. The solution in the platinum crucible was evaporated to dryness after the addition of 2 drops of pure sulphuric acid, first on a water bath and finally on the electric hot plate. The dry residue was ignited for 5 minutes in the electric oven at 600°-700°. After weighing, the residue was again treated with 1 drop each of nitric and sulphuric acids, the acid evaporated, and the lead sulphate again weighed after ignition as before.[8] An alternative procedure consists in precipitating the lead sulphate by dilute sulphuric acid and alcohol after the nitric acid has been removed by evaporation. The lead sulphate is filtered through a platinum filterstick, previously weighed with the platinum crucible, and weighed after drying in an oven followed by ignition for 5 minutes at 600°-700°. Filtrate F_4 was acidified with a few drops of HCl, diluted with water to 2 cc., and hydrogen sulphide passed in. The precipitate of sulphur together with a very small amount of sulphides was filtered through a porcelain filterstick, and washed several times with a little H_2S water, the filtrate being rejected. The mixture of sulphur and sulphides was treated in the crucible with hot HCl (1 : 1), the solution filtered through the filterstick into a porcelain crucible (previously ignited and weighed) followed by several rinsings with hot water. After evaporation of the solution to dryness, the chlorides in the residue are treated repeatedly with nitric acid, and the whole finally evaporated, ignited and weighed. This residue was always so small in amount that it was not possible to confirm the presence of Sn or Sb in it.[9]

Filtrate F_8 was evaporated to dryness in the porcelain crucible, and the residue moistened with a few drops of water. After adding 2 drops of nitric acid to oxidise it, the solution was again evaporated, the residue taken up with 8 cc. of water and 5 drops of HCl, and 0.5 g. of hydroxylamine hydrochloride added to the solution which was warmed on the water bath. After 20 minutes heating, ammonia (recently distilled, and free from carbon dioxide) was added in large excess, and the covered crucible and contents heated for a further period of 30 minutes. A few more drops of ammonia were added, until the liquid had a distinct odour of ammonia, and the precipitate produced was filtered through a porcelain filterstick into a porcelain crucible, the residue being washed with hot water containing ammonium chloride and a small amount of ammonia. The precipitate so obtained consists of the hydroxides of Fe, Al, Th, and the rare earths. The filtrate F_5 contains the uranium as a dark yellow complex salt, and also calcium and magnesium.[10] The above separation with hydroxylamine is due to P. Jannasch,[11] but has rarely been applied to the analysis of pitchblende. It was employed for the first time in the separation of uranium from the rare earths by the author and one of his co-workers, H. Krafft-Ebing.[12]

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[8] No other element of the H_2S group was present.

[9] This is given in the analysis as "SnO_2."

The hydroxides were dissolved in a few drops of hot water and HCl, and the solution filtered through the filterstick into a porcelain crucible. This procedure is necessary in order to recover that portion of the solution which was in the stem of the filterstick, and would otherwise have escaped the subsequent treatment. A better procedure, however, is as follows: The capillary tube (see Fig. 1) is cut above the point *c* and directly connected with the filterstick by means of a rubber tube, without the filterstick being removed from the crucible in which precipitation originally took place. Acid is then sucked through the capillary tube from the end *a*, followed by several rinsings with water. This procedure obviates the necessity for using a second crucible, as the reprecipitation is carried out in the crucible originally employed. 0.5 g. of the hydroxylamine hydrochloride was added to the solution of the hydroxides, the whole warmed for 20 minutes and carbonate-free ammonia added. The liquid was then heated for 30 minutes on the water bath, a little more ammonia introduced, and the liquid filtered into the same crucible previously used to collect filtrate F_5; this filtrate had in the meantime been partially evaporated. The whole operation was repeated a third time, using 0.3 g. of hydroxylamine hydrochloride, and the united filtrates, F_5, concentrated on the water bath until bubbles of gas appeared, due to the decomposition of the hydroxylamine. The crucible was then covered with the glass ball (shown in Fig. 3) and nitric acid added little by little to the solution (which was heated meanwhile continuously on the water bath) until the evolution of gas ceased. The glass ball was then removed and rinsed, and the solution again concentrated. So soon as fresh evolution of gas commenced, the ball was replaced in position and nitric acid carefully introduced. When, after the lapse of some time, the evolution of gas finally ceased, the ball was removed and the solution could then be evaporated to dryness without risk of loss through effervescence. The procedure described is somewhat tedious, but on its completion not only the hydroxylamine but also the greater part of the ammonium salts present have been destroyed.

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[10] Komarowsky, A. S., and Goremykin, W. J., Ztschr. analyt. Chem., **87**, 339, 1932.

[11] Jannasch, P., and Schilling, J., Journ. prakt. Chem., 72, 26, 1905; Jannasch, P., l. c. 35; Becker, A., and Jannasch, P., Jahrbuch für Radioakt. u. Elektronik, 12, 9, 1915.

[12] These experiments are not yet published.

The residue was evaporated twice with a few drops of HCl, dissolved in 6 cc. of water and 5 drops of HCl, 0.5 g. of hydroxylamine hydrochloride added, and the separation repeated once more in order to remove small quantities of the hydroxides which had passed into the filtrates containing the uranium during the three previous treatments. A reprecipitation of small amount of hydroxide obtained is unnecessary; it can be regarded as free from uranium for practical purposes. The filtrate was treated with nitric acid in the manner previously described in order to remove hydroxylamine and ammonium salts.

The third precipitate of hydroxides, together with the small additional precipitate mentioned above, were heated in the crucibles together with the filtersticks with 5 drops of nitric acid and a little water in each case. The solutions were both sucked over into the same platinum crucible (previously weighed together with its filterstick), washing being carried out with hot dilute nitric acid. The volume of the solution was reduced to 6 cc., and 1.5 cc. of a cold saturated solution of oxalic acid was added drop by drop, whereby a precipitate of the oxalates of thorium and a part of the rare earths was obtained. After standing overnight the solution was filtered into a platinum crucible which had previously been weighed together with its filterstick. The wash liquid employed consisted of a mixture of 1 part of a cold saturated solution of oxalic acid and 3 parts of water; it was used hot, washing being carried out with three portions of 1 cc. each time. The crucible, filterstick and precipitate were first dried in an oven at 110°, and then gradually heated in an electric oven, finally being ignited at 1000° for 5 minutes. The weighted residue represented the oxides of thorium and the rare earths. The filtrate F_6 was rendered feebly ammoniacal, neutralised with nitric acid in the presence of phenol phthaleine as indicator (the volume being 6-8 cc.) and 6 drops of acid in excess added, and the whole heated on the water bath for some time, when a fresh precipitate, consisting of the remainder of the rare earths present, generally appeared; whenever possible, this precipitate was allowed to stand overnight. Next day, the solution was sucked over into a porcelain crucible, and the residue washed several times with the dilute oxalic acid solution previously mentioned (this solution was partially neutralised with ammonia in this case before use). The crucible, filterstick and precipitate were ignited as in the previous case, and the weight obtained represented the remainder of the rare earths.

The ignited oxides of thorium + the first portion of the rare earths were subjected to the following treatment in order to separate the thorium from the remaining earths. A small quantity of potassium pyrosulphate was placed in the crucible containing the filterstick and the oxides, and the whole heated, at first gently, and finally to redness. Any particles of oxide which had adhered to the sides of the crucible were brought into contact with the molten pyrosulphate by carefully moving the filterstick up and down the sides by means of platinum-tipped forceps, so that complete attack on the oxides was thus attained. After cooling, the crucible was half filled with water, 15-20 drops of nitric acid were added, and the whole heated on the water bath until complete solution resulted. The resulting solution was transferred by suction to a porcelain crucible, followed by several rinsings with hot water, and the whole heated on the water bath after having been made strongly ammoniacal. The hydroxides separated under these conditions in a flocculent state, and could be readily filtered. They were filtered through a porcelain filterstick, washed with hot water containing a little ammonia and ammonium nitrate, and redissolved in the same crucible by sucking in hot dilute nitric acid from the end *a* of a capillary tube (Fig. 1) in the manner previously described. After rinsing several times with hot water and evaporation to a volume of 3 cc., the precipitation by ammonia followed by filtration and washing was repeated. The second precipitate was redissolved by warming with water and a few drops of nitric acid, and the solution transferred through a filterstick into another porcelain crucible. The oxides of the second portion of rare earths were dissolved by warming with 1 cc. of 1:1 nitric acid, and the solution sucked over through the platinum filterstick into the porcelain crucible containing the nitrates of thorium and the first portion of the rare earths; no thorium is, however, likely to be present in this second portion of rare earths. The nitric acid solution was evaporated to dryness, the residue moistened with water, and the whole again evaporated; this process was then carried out a third time, in order to ensure complete expulsion of the acid. Twenty drops of a 10% solution of ammonium nitrate were added, and after warming on the water bath for a short time 7-10 drops of 3% hydrogen peroxide were introduced, whereupon a gelatinous precipitate of hydrated thorium peroxide formed, which filtered extremely readily. The solution was transferred through a porcelain filterstick into a platinum crucible (previously weighed together with its filterstick), and the residue washed with a hot, 10% solution of ammonium nitrate (Filtrate F_{10}). The precipitate of thorium peroxide was dissolved in dilute nitric acid, the solution transferred to a platinum crucible (previously weighed together with its filterstick), and evaporated to dryness. The residue was twice re-evaporated after being moistened with water each time, and finally taken up with 10% ammonium nitrate solution and the thorium reprecipitated with hydrogen peroxide, etc., in the manner given above. The filtrate was added to F_{10}. The crucible, filterstick and precipitate were dried first at 110°, and then heated in an electric oven, the temperature being gradually increased until the precipitate had been maintained for a few minutes at 1000°.

The weight of the ignited residue gave the thoria. The united filtrates can be further treated in the following way, if one does not wish to obtain the value for the rare earths from the difference between the total weight of oxides and that of the thoria determined as above. They are diluted to 4 cc., and 2 drops of nitric acid and 10 drops of a cold saturated solution of ammonium oxalate are added. After standing for 12 hours, the precipitate of rare earth oxalates is filtered off, ignited to oxides, and weighed.

The filtrate F_7, which contains Fe and Al, was concentrated on the water bath so far as possible, and treated with 10 drops each of perhydrol and HCl, and a few drops of water. The crucible was at once covered with the glass ball, which was only removed and rinsed when all evolution of gas had ceased. The solution was evaporated so far as possible, 10 drops of nitric acid were added, the solution evaporated, more nitric acid introduced, and the whole evaporated to dryness. The crucible was then placed in a drying oven and kept at 190°-200° for some time, and finally heated on an electric hot plate. In the majority of cases the ammonium salts and the greater portion of the oxalic acid will have been already removed by the treatment on the water bath, but by the method described above the whole of the remaining oxalic acid can be destroyed without risk of loss. The residue is dissolved in a few drops of HCl and water, the liquid evaporated to dryness, the residue taken up with 4 drops of nitric acid and a little water, evaporated to dryness, and once more moistened with a few drops of nitric acid and hot water. The solution is transferred through a porcelain filterstick to a platinum crucible (previously weighed together with its filterstick) and diluted to 2 cc. Ammonia is added until its odour just persists, and the whole is warmed on the water bath for 10 minutes when a further drop of ammonia is added. The liquid is filtered through the platinum filterstick, and the precipitate washed with a hot 1% solution of ammonia, containing a little ammonium nitrate; the filtrate is rejected. The crucible, filterstick and precipitate are first dried at 110° and then ignited for 5 minutes in the electric oven at 1000°; the ignited precipitate consists of ferric oxide and alumina. The above two constituents may be separated if desired by the following method. Fusion with potassium pyrosulphate, followed by solution in 5 drops of HCl and 3 cc. of hot water, transference of the solution to a porcelain crucible, and saturation of the liquid with hydrogen sulphide. The precipitated platinum sulphide is filtered off through a porcelain filterstick, and the solution received in another porcelain crucible which has previously been weighed together with its filterstick. 0.1 g. of tartaric acid is added, and hydrogen sulphide passed in. Ammonia is added until its odour definitely persists, and more hydrogen sulphide introduced. The solution is filtered through the porcelain filterstick, and the residue washed three times with a very dilute solution of yellow ammonium sulphide. The residue is dried at 110°, ignited for 5 minutes at 1000°, and weighed as ferric oxide.

The filtrate F_6 was further treated as follows: After removal of the hydroxylamine, the residue from the evaporated solution, which contained nitrates of U, Ca and Mg, was dissolved in the least possible amount of hot water, and the solution transferred with the aid of a bent capillary tube through a porcelain filterstick into a Jena micro filterbeaker (Fig. 5) which had previously been dried at 110° to constant weight. It was washed with hot water, care being taken to see that the total volume of the filtrate and washings did not exceed 3 cc. The employment of a filter is necessary when transferring the solution to the micro beaker, as the evaporation of the ammoniacal solution liberates small amounts of silica, probably derived from the porcelain crucible. Furthermore, the employment of a filterstick in this and similar cases permits of a very slow and undisturbed transference of the solution, and obviates the possible introduction of accidental impurities. These, and similar refinements of procedure, which may perhaps seem to be of little importance to the reader who has no practical experience of micro-gravimetric analysis, exert in reality a very great influence on the success of a micro-analysis which is so complicated as the one under discussion.

Five drops of a concentrated solution of ammonium acetate were introduced into the micro filterbeaker, and after heating to 80° a large excess of the 8-hydroxyquinoline reagent was added drop by drop.[18] The amount of free acetic acid must not exceed 2%. After cooling to room temperature the beaker was connected with the suction apparatus and the solution drawn over into a porcelain crucible, the residue being rinsed three times with hot water whilst rotating the beaker. In order to exclude dust, a Jean glass filter (with sintered plate) was fitted by means of a cork into the wide neck of the beaker (Fig. 5, left-hand side). The beaker was placed in a drying oven at 110°, and a rapid current of air aspirated through it for 20-30 minutes. It was then wiped, first with a moist and then with a dry chamois leather, allowed to stand in the open balance case for 30 minutes, and then weighed. The weight of the precipitate gave that of the "oxine" of uranium (abbreviation for hydroxyquinolate) which is multiplied by 0.3386 to give the corresponding amount of uranium.

The filtrate F_8 was evaporated to dryness in a porcelain crucible, the residue covered with sublimed oxalic acid, and gently ignited. It was then moistened with a few drops of dilute nitric acid, evaporated to dryness, the residue dissolved

[18] Determination of uranium with 8-hydroxyquinoline; Hecht, F., and Reich-Rohrwig, W., Monatshefte für Chemie, **53** and **54**, 596, 1929; see also Hecht, F., Mikrochemie, **10**, 49, 1931.

in hot water and the solution transferred to a micro filterbeaker with the aid of a bent capillary tube, as previously described. The beaker in question had been previously weighed after drying at room temperature whilst a current of dust-free air was aspirated through it. The volume of solution in the beaker must not exceed 2 cc.; if it does, it must be reduced to this volume by heating at 80° in a drying oven in a current of dust-free air, a Jena glass filter tube being meanwhile inserted into the wide neck as previously mentioned. The calcium was then precipitated by the addition, drop by drop, to the solution heated to 50°, of twice the theoretical amount of the picrolonic acid reagent.[14] The precipitate was allowed to stand for some hours in an ice-chest or refrigerator, and was then filtered and washed twice with 0.2-0.3 cc. of ice-cold water each time. The precipitate was dried at the ordinary temperature by aspirating a rapid current of air through the beaker with the dust filter in position. The weight of the dried precipitate multiplied by 0.05641 gives the calcium.

The filtrate F_0 which had been collected in a porcelain crucible was evaporated to dryness, the residue carefully ignited, and dissolved in 2 drops of HCl and 0.5 cc. of hot water. The solution was sucked over into a Jena micro filterbeaker (previously dried to constant weight at 105°), a few drops of a saturated solution of ammonium chloride and 3 drops of ammonia were added, the whole heated to 70° and the magnesium precipitated by an excess of a 1% alcoholic solution of 8-hydroxyquinoline.[15] The precipitate was filtered after standing for 30 minutes, washed alternately with water containing a little ammonia, and alcohol, and finally with alcohol alone. The beaker and precipitate were then dried for 30 minutes at 105°, and the magnesium determined by multiplying the weight of the dried precipitate by 0.0698.[16]

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[14] Determination by the method of R. Dworzak and W. Reich-Rohrwig, Ztschr. analyt. Chem., **86**, 98, 1931. In order to obtain a N/100 solution of picrolonic acid, 2.64 g. of Merck's or Kahlbaum's preparation was dissolved in 1 litre of water with the aid of heat, and the solution cooled to room temperature. A small residue—presumably picrolonic acid—is filtered off, and a saturated (N/100) solution of the reagent is thus obtained.

[15] Determination by the method of R. Strebinger and W. Reif, Mikrochemie, Pregl-Festschrift, 319, 1929.

[16] In previous analyses Mg was precipitated as $MgNH_4PO_4$, ignited and weighed as $Mg_2P_2O_7$. The determination by means of 8-hydroxyquinoline is preferable, and the former method is consequently not described here.

Determinations of moisture were carried out in a very small porcelain crucible, 5-10 mg. of the mineral being dried in an oven at 110° to constant weight (which usually required 2 hours). The crucible was then heated in an electric oven at 300° until constant in weight (usually 2 hours). Finally it was ignited at 1000° for 10-15 minutes in order to determine the loss on ignition.

In order to determine the ratio UO_2/UO_3 4-6 mg. of the mineral were placed with dilute sulphuric acid (1 : 6) in a glass tube closed at one end. The air was displaced by CO_2. The tube was sealed whilst introducing CO_2 and heated in a micro bomb oven at 175°; 2-3 hours were sufficient to ensure complete attack. After cooling to the ordinary temperature the tube was opened and the uranium determined as rapidly as possible by titration with N/100 potassium permanganate. A more detailed description of this method, which has been worked out by the author and his co-worker, H. Krafft-Ebing, will be published shortly in another journal. (The above volumetric method was described by W. F. Hillebrand[17] for *macro*-analysis in 1891.)

It is evident that the micro methods just described will yield good results only in the hands of an analyst who has acquired considerable experience in this specialised branch. On this account it seemed necessary to me to give a detailed account of the procedure. All the operations must be carefully carried out with the greatest possible precautions. If this is done, however, then micro-analysis shows a great saving of time, labour, materials and reagents as compared with the usual macro methods.

Furthermore, it must be mentioned that my collaborators and myself have for some time past been working on the application of micro methods to the analysis of other radioactive minerals, such as kolm-ash, cyrtolite, thucholite, monazite, allanite and wiikite. A certain amount of preparatory work on the last-named mineral was carried out by Dr. L. Lokka and myself two years ago.

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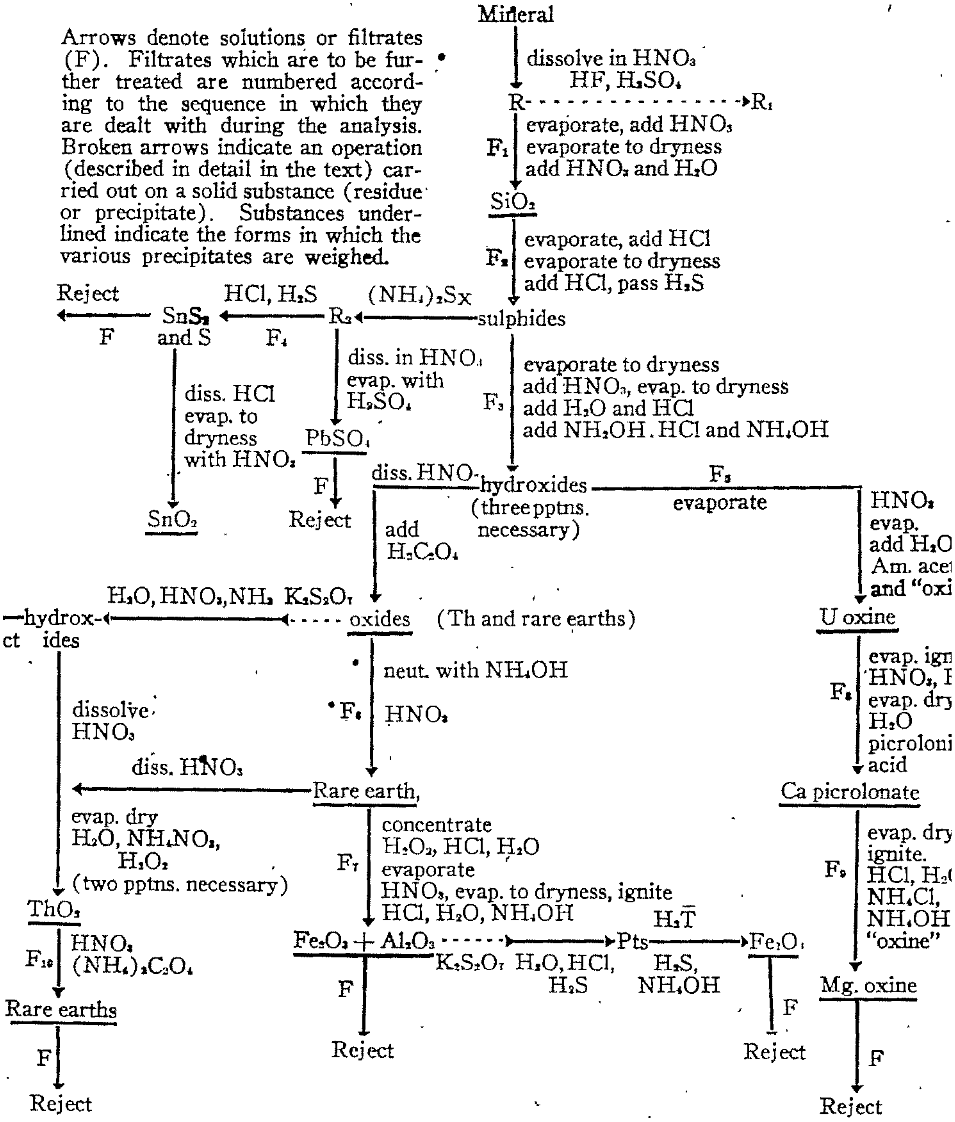
[17] Hillebrand, W. F., Bull. Geol. Survey, U. S. No. 88, p. 49, 1891.

Scheme for the Analysis of a Pitchblende.


Mineral
dissolve in HNO_3 HF, H_2SO_4
R
R_1
F_1
evaporate, add HNO_3 evaporate to dryness add HNO_3 and H_2O
SiO_2
F_2
evaporate, add HCl evaporate to dryness add HCl, pass H_2S
sulphides
$(NH_4)_2Sx$
R_2
HCl, H_2S
F_4
SnS_2 and S
F
Reject
diss. HCl evap. to dryness with HNO_3
SnO_2
diss. in HNO_3 evap. with H_2SO_4
$PbSO_4$
F
Reject
F_3
evaporate to dryness add HNO_3, evap. to dryness add H_2O and HCl add $NH_2OH.HCl$ and NH_4OH
hydroxides (three pptns. necessary)
diss. HNO_3
add $H_2C_2O_4$
F_5
evaporate
HNO_3 evap. add H_2O Am. acet and "oxi
U oxine
F_8
evap. ign HNO_3, I evap. dry H_2O picroloni acid
Ca picrolonate
F_9
evap. dry ignite. HCl, H_2O NH_4Cl, NH_4OH "oxine"
Mg. oxine
F
Reject
oxides (Th and rare earths)
$K_2S_2O_7$
H_2O, HNO_3, NH_3
hydrox-ides
ct
dissolve HNO_3
neut. with NH_4OH
F_6
HNO_3
Rare earth,
diss. HNO_3
evap. dry H_2O, NH_4NO_3, H_2O_2 (two pptns. necessary)
ThO_2
F_{10}
HNO_3 $(NH_4)_2C_2O_4$
Rare earths
F
Reject
F_7
concentrate H_2O_2, HCl, H_2O evaporate HNO_3, evap. to dryness, ignite HCl, H_2O, NH_4OH
$Fe_2O_3 + Al_2O_3$
F
Reject
$K_2S_2O_7$
H_2O, HCl, H_2S
Pts
H_2T
H_2S, NH_4OH
Fe_2O_3
F
Reject

Arrows denote solutions or filtrates (F). Filtrates which are to be further treated are numbered according to the sequence in which they are dealt with during the analysis. Broken arrows indicate an operation (described in detail in the text) carried out on a solid substance (residue or precipitate). Substances underlined indicate the forms in which the various precipitates are weighed.

D. ANALYSES OF GORDONIA URANINITE.

The powdered mineral A was treated for 5 hours with HCl (1 : 1), and the insoluble part (sample A′) was finely powdered and dried at 110° to constant weight. The analysis of the HCl extract (sample A″) was referred to the sum total of the oxides contained in the solution after removal of insoluble silica (which constituted about 4% of the whole); these oxides were: soluble SiO_2, PbO, Fe_2O_3, Al_2O_3, ThO_2, rare earths, U_3O_8, CaO, MgO. In order to determine these, two portions of 5 cc. each of the extract were converted to nitrates in a porcelain crucible, and then ignited to oxides; the weights obtained in both cases coincided almost absolutely. Portions of 5 cc. of solution were also employed for the analyses. Determinations of the hygroscopic water and loss on ignition were carried out on separate weighed quantities of material. The macro-analyses used as a check were carried out by M. v. Mack.

	A′ (residue after treatment with HCl)		A″ (HCl-extract)	
	Micro	Macro	Micro	Macro
Weight of sample	32 mg.	1.02 g.	45 mg.	2.17 g.
Insoluble residue	8.45%	8.34%	.....%	.....%
(of which SiO_2)	(6.92)	(6.94)	.....	.....
SiO_2 soluble	0.35	0.10	0.41	0.32
PbO	10.99	11.04	10.17	10.25
(Pb)	(10.20)	(10.25)	(9.44)	(9.51)
SnO_2?	0.20	0.13	.....	.....
Rare earths	3.00	3.10	1.92	2.55
ThO_2	13.29	13.55	6.26	5.98
(Th)	(11.68)	(11.91)	(5.50)	(5.26)
$Fe_2O_3 + Al_2O_3$	7.26	n.d.*	1.41	1.54
UO_2	26.45	50.70†	75.30†	75.85†
UO_3	23.60			
(U)	(42.96)	(43.00)	(63.85)	(64.32)
CaO	1.75	1.45	2.40	2.38
MgO	0.39	0.24	0.07	0.24
H_2O (–300° C)	2.58	2.19	.....	.....
Loss on ignition (300-1000° C)	2.02	1.79	.....	.....
Total	100.33%	.....%	97.94%	99.11%

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* Not determined.

† Calculated as U_3O_8.

	B Micro	B′ Micro	B′ Micro
Weight of sample	23 mg.	24 mg.	26 mg.
Insoluble residue	2.76%	0.46%	
(of which SiO_2)	(1.41)	n.d.	
SiO_2 soluble	1.92	0.02	
PbO	10.13	11.13	10.87
(Pb)	(9.40)	(10.33)	(10.09)
SnO_2?	.....	0.31	
Rare earths	1.05	2.81	16.32
ThO_2	9.17	13.37	
(Th)	(8.06)	(11.75)	
Fe_2O_3	0.35	0.42	
Al_2O_3	0.81	1.83	
UO_2	17.40	31.99	64.85
UO_3	51.50	32.20	
(U)	(58.20)	(55.00)	(55.00)
CaO	1.11	3.00	
MgO	0.11	traces	
H_2O (–110°)	0.94	0.05	
H_2O (110-300°)	2.23	0.09	
Loss on ignition (300-1000°)	0.82	0.73	
Total	100.27%	98.41%	

B—original sample, untreated with HCl, finely powdered.
B′—handpicked material, untreated with HCl, finely powdered.

CONTROL ANALYSIS OF AN "ARTIFICIAL PITCHBLENDE."

For the purpose of obtaining an exact check on the methods, an "artificial pitchblende" was made up by mixing accurately standardised solutions, and the resulting final solution was analysed by the micro methods previously described. A slight modification was introduced, in that the Fe and Al were not determined together as oxides after ignition of the ammonia precipitate, but the two metals were weighed together as 8-hydroxyquinolates,[18] the Fe being then separated by ammonium sulphide in presence of tartaric acid. The FeS was dissolved in HCl, the solution evaporated, filtered from separated sulphur, and the Fe precipitated and weighed as 8-hyroxyquinolate in a Jena micro filterbeaker, the Al being then obtained by difference. It may be pointed out in this connection that the Jena micro filterbeaker permits of a perfectly satisfactory filtration of the Fe oxine precipitate (either alone or in conjunction with the Al oxine), a turbid filtrate never being obtained. SiO_2 or silicates were not used in this arti-

[18] Benedetti-Pichler, A., Mikrochemie, Pregl-Festschrift, p. 6, 1929; Benedetti-Pichler, A., and Schneider, F., Mikrochemie, Emich-Festschrift, p. 1, 1930.

ficial mixture, as the presence of appreciable quantities of alkalis interferes with the precipitation of the Ca as picrolonate, and renders a preliminary separation as oxalate necessary. The reliability of the method used for the determination of the silica is, however, evident from a comparison of the results afforded by the micro- and macro-analyses of specimens A′ and A″ (page 340).

	Present		Found		Present		Found	
	mg.	mg.	mg.	mg.	%	%	%	%
PbO	2.890		2.879		9.96		9.91	
Rare earths ...	1.978	5.879	5.882	1.901*	6.82	20.26	20.26	6.55*
ThO_2	3.901			3.957*	13.44			13.63*
Fe_2O_3	0.823	2.074	2.073	0.850*	2.84	7.15	7.15	2.93*
Al_2O_3	1.251			1.223†	4.31			4.22†
U_3O_8	17.842		17.920		61.47		61.74	
CaO	0.287		0.393‡		0.99		1.36‡	
MgO	0.052		0.093‡		0.18		0.32‡	
Total	29.024		29.240‡		100.01%		100.74%	

Analysts; F. Hecht and H. Krafft-Ebing.

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* After separation.

† Calculated from the oxine determinations of Fe and Fe + Al.

‡ Owing to the rather considerable discrepancy in these values for CaO and MgO, a further determination of these two constituents was carried out in another portion of material, with the following results:

CaO .... 0.286 mg., corresponding to 0.985%
MgO .... 0.037 mg., corresponding to 0.13%
Total .... 29.077 mg.

E. Acknowledgments.

It is a pleasure for me to express my indebtedness to Professor A. Franke, Director of the Analytical Laboratory of Vienna University, for the great interest he has shown in all my work, and for placing all the necessary laboratory facilities at my disposal; also to the Elizabeth Thompson Science Fund in Boston for a grant which defrayed the cost of a micro balance and accessories, and to Professors A. C. Lane, G. P. Baxter, and G. Kirsch, for having kindly recommended this grant. I wish to thank the Editors and Publisher of *Mikrochemie* for permission to reproduce the diagrams and also the Editors of this Journal for having had them specially redrawn and lettered in English. A special word of acknowledgment is due to Dr. H. F. Harwood (Imperial College of Science and Technology, London), who most kindly undertook the arduous task of translating this paper into English. For his friendly coöperation I am deeply grateful.

Vienna, Austria.

THE GORDONIA URANINITE AND THE UPPER PRE-CAMBRIAN ROCKS OF SOUTHERN AFRICA.

ARTHUR HOLMES.

I. ANALYSES AND LEAD-RATIOS.

A few weeks before his lamented death in 1929, Dr. P. Wagner sent me two specimens of uraninite from the Gordonia district of the Cape Province of South Africa. These are the samples A and B of the foregoing paper by Dr. F. Hecht, who kindly undertook their analytical investigation. Dr. Wagner described their source as one of a series of coarse pegmatites occurring in the valley of the Back River, about six miles from its confluence with the Orange River. Associated radioactive minerals are fergusonite, gadolinite, and allanite. In a later account of the occurrence of the uraninite, E. D. Mountain (1931, p. 138) states that the farms on which it has been found "appear to lie in a zone running east-west in the south west corner of Gordonia, stretching from Aries Kop, which lies on the border of South West Africa and is about 10 miles south of Nakop, to Narugas, a total distance of some 10 or 15 miles." The belt continues over the border into South West Africa.

Mountain further states that "the pitchblende occurs as crystals and segregations in both pegmatites and quartz veins and is usually characteristically altered at the surface to a deep-yellow decomposition product, probably uranium ochre or gummite." He gives an excellent analysis of an unaltered crystal, the results of which, together with the lead-ratio calculated from them, are as follows:

	Uraninite
UO_2	36.42
UO_3	37.94
ThO_2	9.32
CeO_2	3.20
PbO	9.48
SiO_2	0.73
Fe_2O_3	1.86
CaO	0.63
H_2O	0.82
Insol.	0.21
	100.61

Boksput Farm, Gordonia

$U = 63.69$

$Th = 8.19$

$Pb = 8.80$

$$\frac{Pb}{U + 0.36Th} = 0.131$$

Corresponding to an age of 925 million years.

Analyst. E. D. Mountain, (1931, p. 139).

The criteria adopted by Ellsworth (1932, p. 103) for deciding whether the state of preservation of uraninite is to be rated as *good* or *superior* are listed below, together with the corresponding characters of the analysed specimen.

	Superior Uraninite	Analysed specimen	Good Uraninite
Sp. Gr.	9	8.876	8-9
Hardness	6	*ca.* 5½	<6
Colour	steely black	black	pitch black
Lustre	almost metallic	submetallic	nonmetallic
Fracture	uneven	uneven	conchoidal
UO_2 per cent	50 +	36.42	35-50
SiO_2 per cent	<0.75	0.73	
H_2O per cent	<0.35	0.82	

Although Mountain's specimen was not in the most perfect state of preservation, it was clearly sufficiently fresh to furnish a lead-ratio that can be accepted as a reliable index to age.

Unfortunately, this was far from being true of Wagner's specimens A and B. Both were free from superficial crusts of decomposition products, but A was riddled with cracks occupied by yellow-brown earthy material which was readily soluble in dilute hydrochloric acid. It was obviously in the state of preservation described by Ellsworth as *poor.* Microscopic examination of the crushed material failed to reveal the presence of any silicate minerals such as microcline or mica. Treatment with hydrochloric acid, as described by Davis (1928, p. 203), gave a copious soluble extract A″ (equivalent, when dried at 110°C. to 31% of the sample) and left as insoluble residue a dull dark grey powder A′ free from visible coloured secondary products.

Specimen B was of apparently slightly better quality and consisted of dull black uraninite penetrated by numerous veinlets of earthy decomposition products. The specific gravity at 21°C. was 7.201. Part of the specimen was crushed and passed through a 60-mesh sieve and used for analysis B. The other part was broken up into small fragments. Those that appeared free from visible secondary products were picked out, coarsely ground, washed free from powder, and dried. The splinters were black, and though some were dull, a majority exhibited submetallic lustre. Examination under the microscope revealed a few grains that showed traces of decomposition; these were removed, leaving a clean residue B′. This amounted to 39.4% of the sample. The specific gravity of B′ at 21°C. was 8.582.

Dr. Hecht's analyses of the four materials so prepared are recorded on pages 340 and 341 of the preceding paper. The following results are those required for the present discussion:

	A′ Residue		A″ Extracted by HCl		B Untreated	B′ Hand-picked
	Macro	Micro	Macro	Micro	Micro	Micro
U_3O_8	50.70	(50.66)	75.85	75.30	.....	.....
UO_2	.....	26.45	.....	.....	17.40	31.99
UO_3	.....	23.60	.....	.....	51.50	32.20
ThO_2	13.55	13.29	5.98	6.26	9.17	13.37
PbO	11.04	10.99	10.25	10.17	10.13	11.00
U	43.00	42.96	64.32	63.85	58.20	55.00
Th	11.91	11.68	5.26	5.50	8.06	11.75
Pb	10.25	10.20	9.51	9.44	9.40	10.21
$\frac{Pb}{U + 0.36\ Th}$....	**0.217**	**0.216**	**0.144**	**0.143**	**0.154**	**0.172**
Insoluble residue	8.34	8.35	.....	.....	2.76	0.46
SiO_2	7.04	7.27	0.32	0.41	3.33	n.d.
H_2O + ignition..	3.98	4.60	.....	.....	3.99	0.87

It is well known that altered uraninites generally yield lead-ratios that are too high (compared with the values corresponding to the geological age) as a result of the tendency for uranium present as UO_8 to be leached out in relatively higher proportion than lead (Ellsworth, 1930, p. 458; Holmes, 1931, p. 432). The altered Gordonia uraninites conform to the "rule," as the following comparative figures clearly show:

Sample A	A′ (69%) Altered Uraninite* (residue after HCl treatment)	A (100%) Original Sample (Calculated)	A″ (31%) HCl Extract (including Secondary Products)
U	49.32	57.09	63.85
Th	13.41	9.04	5.50
Pb	11.71	10.46	9.44
$\frac{Pb}{U + 0.36\ Th}$	0.216	0.173	0.143

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* Recalculated from the analysis after subtracting insoluble residue, water, and loss on ignition to give figures comparable with those of A″.

Sample B	B′ (39.4%) Hand-picked uraninite S.G. = 8.582	B (100%) Original Sample S.G. = 7.201	B″ (60.6%) Residue including Secondary Products (Calculated)
U	55.00	58.20	60.28
Th	11.75	8.06	5.66
Pb	10.21	9.40	8.88
$\frac{Pb}{U + 0.36\ Th}$	0.172	0.154	0.144

The lead-ratio of Mountain's fresh crystal is 0.131. That of the altered specimen B is 0.154, while the still more altered specimen A gives 0.173. It had been hoped, however, that the handpicked material B′ would give a lead-ratio appropriate to the fresh mineral. Actually, the ratio of B′ is still higher than that of B. This is the more remarkable, because the analysis of B′ conforms with its relatively fresh appearance. The low silica (less than 0.46%) and the moderate water content would both suggest that there had been no serious alteration. Indeed, the material falls short of what Ellsworth would class as "good" only in the fact that UO_2 is below the lower limit for that class. It would appear that the state of oxidation is a more sensitive guide to the degree of freshness or alteration than the other criteria, for there seems to be no satisfactory alternative to the conclusion that the material B′ has suffered a considerable loss of uranium, with consequent relative gain in thorium and lead.

The figures for the B series reveal the effects of purely natural processes of alteration. In the A series these effects have been carried a stage further by the leaching action of hydrochloric acid, with the result that A′ contains less uranium than B′ and correspondingly more thorium and lead.

The effect of hydrochloric acid on uraninites and pitchblendes appears to depend partly on the strength of the acid, but mainly on the state of oxidation of the uranium. Uraninites that are rich in UO_2 are unaffected by dilute hydrochloric acid (e.g. 1:10). To investigate the effect of stronger acid Dr. Hecht carried out a test on a sample of powdered uraninite from Strickland quarry, Connecticut, that had already been analysed (Hecht, 1932, p. 287, No. 7). The powder was treated with 1:1 acid at room temperature over night and then warmed on a water bath for one hour. Of the original 156.608 mg. of uraninite, 5.781 mg. passed into solution. Dr. Hecht's analysis of the dissolved material is given below with that of the original sample for comparison.

Strickland, Conn., U. S. A.	Original Sample		Soluble Extract
U_3O_8	(92.83)		76.81
UO_2	75.41		.....
UO_3	14.83		.....
ThO_2	2.59	(2.87)	8.98
Rare earths	0.28		
PbO	3.94		7.92
$Fe_2O_3 + Al_2O_3$	0.53		3.96
CaO	0.30		1.78

Evidently lead and thorium have here been extracted in relatively greater proportion than uranium.

On the other hand when UO_3 is abundant and the crystal lattice has degenerated, even dilute hydrochloric acid becomes a powerful solvent. One of the thorium-free Katanga pitchblendes analysed by Körner and Hecht (1928, p. 456) was treated with 1:10 acid and the soluble extract and insoluble residue were separately analysed. The pertinent results are:

Katanga	Sample KVB Insoluble Residue	Sample KV Original Sample (Calculated)	Sample KVA Soluble Extract
U	72.88	71.23	70.85
Pb	8.22	6.85	4.49
$\frac{Pb}{U}$	0.113	0.096	0.063

From this mineral, as from the Gordonia specimen A, the acid has extracted uranium in far higher proportion than lead, leaving a residue with a correspondingly high lead-ratio.

Returning to the Gordonia specimen B, it might be argued that the high lead-ratio of B′ is not a result of alteration, but is a genuine indication of the geological age of the mineral. There are two objections to this view. If B′ represented the original unaltered mineral, then the effect of alteration must have been to abstract lead and thorium in greater relative amount than uranium, leaving secondary products B″ impoverished in the former elements. Such, indeed, was the effect of acid on the Strickland uraninite, but the latter had 75.41% of UO_2, whereas B′ had only 31.99% and the chemical responses in the two cases are therefore not comparable. The usual effect of natural alteration (and the actual effect of acid on specimen A) is to abstract uranium in greater relative amount than thorium and lead, and there is no reason for supposing that the natural alteration of specimen B went in the opposite direction (see Ellsworth, 1932, p. 243).

A second objection against accepting a lead-ratio of 0.172 for the Gordonia uraninite is that the lower ratio of 0.131 obtained by Mountain from good material is supported by certain other analyses that have been made for commercial purposes. These have been communicated to me by Mr. Mountain and are given in the following table:

Gordonia	I	II	III
U_3O_8	80.05	33.26	69.97
UO_2	.....	38.50	.....
ThO_2, etc.	7.20	12.17	4.75
PbO	8.90	8.52	9.94
SiO_2	0.45	0.70	7.90
Al_2O_3	n. d.	0.14	1.34
Fe_2O_3	n. d.		2.39
MgO	tr.	n. d.	n. d.
CaO	0.80	n. d.	tr.
H_2O, etc.	2.00	7.40	4.20
	99.40	100.69	100.49
Sp. gr.	8.88	8.84	.....
U	67.88	62.16	59.33
Th	< 6.33	< 10.70	< 4.18
Pb	8.26	7.91	9.22
$\frac{Pb}{U + 0.36\,Th}$	0.118 +	0.128 +	0.152 +

I. Analyst—Mr. G. Green (National Bank of South Africa Ltd.)
II. Analyst—Mr. J. Parry (de Beers Consol. Mines. Ltd.)
III. Analyst—Mr. Robson (The Royal Mint, Pretoria).

The material of No. III appears to have been altered, judged by its high silica content, and the lead-ratio, as would be expected, is high. Referring to I and II, Dr. Hecht points out that the very low totals for the group of oxides Al_2O_3, Fe_2O_3, MgO, and CaO are improbable, and draws attention to the analytical difficulty of separating iron, aluminum, thorium, and the rare earths from uranium. A moderate allowance for these discrepancies (based on his own analyses) decreases the uranium content and increases the lead-ratios from 0.118 to 0.127 (I) and from 0.128 to 0.134 (II). Application of a similar "correction" to Mountain's analysis, which is of much better quality, would increase the ratio from 0.131 to 0.133. It may be pointed out that if the still doubtful factor k (in the expression $U + k\text{Th}$) be taken as 0.25 instead of 0.36, the ratios are not increased by more than 0.002.

It is therefore concluded with some confidence: (a) that a lead-ratio near 0.13 corresponds approximately to the age of the Gordonia uraninite; (b) that the material B′, though apparently fairly fresh, is a leached residual product that has lost uranium in relatively greater amount than thorium and lead and yields in consequence a lead-ratio that by itself would be misleadingly high.

The second of these conclusions may be thought to have a bearing on the interpretation of the remarkably high lead-ratios found by Davis (1928, p. 209) for the South Dakota uraninite (0.225) and by Ellsworth (1931, p. 572) for the Manitoba uraninite (0.260). It is probable that had B′ been the only analysed sample of Gordonia uraninite, its lead-ratio would have been tentatively accepted as being approximately correct. The analytical results bear a striking resemblance to those for the Wilberforce (Cardiff, Ontario) uraninite (Ellsworth, 1932, p. 268), and neither the chemical nor the physical characters of the material B′ would have suggested that its lead-ratio was too high by over 30 per cent. However, it must be clearly stated that both Davis and Ellsworth give adequate evidence that the uraninites they analysed were of first class quality and that dilute hydrochloric acid had no effect on anything but the associated traces of soluble secondary minerals. I can see no good reason to cast suspicion on these high ratios in the light of Dr. Hecht's work on the Gordonia uraninites.

II. GEOLOGICAL AGE AND CORRELATIONS.

It is now becoming widely recognised that lead-ratios, wherever they are available, provide the most reliable means yet available for determining the ages of igneous rocks and establishing their correlations. The method is of unique importance in dealing with the difficult problems of the pre-Cambrian, and as I have already shown (Holmes, 1931, p. 441), certain long-distance correlations can now be made with reasonable confidence. The following list gives the data from which the position of the Gordonia pegmatites is inferred:

Minerals and Localities	Lead-ratios
Uraninite, Gordonia	*ca.* 0.13
Bröggerites, Moss, Norway	0.125-0.135
Uraninite, Gaya, India	0.12 -0.13
Uranium ore, Radium Hill, South Australia	*ca.* 0.13

The minerals from Norway, India, and South Australia are associated with granites known to be of late Middle pre-Cambrian age, and the Gordonia pegmatites may therefore be referred to the same period.

The region in which the Gordonia uraninites occur forms part of a widespread tract of the rocks characteristic of the Basal Complex of South Africa. For the most part these consist of gneisses, granitic rocks, and pegmatites, interrupted at intervals by lenticular strips of the schists and granulites of the older Kheis Series. The latter represents a long sequence of sedimentary and volcanic formations. Mountain building, accompanied by granite intrusion and the formation of gneisses and migmatites and succeeded by an abundant suite of pegmatites, brought the cycle to a close. The pegmatites are commonly parallel to the regional foliation, but others cut across the banding. Both sets are themselves free from foliation.

To the east a similar complex is found in the Mafeking area; the old gneissose granites and its associates are encountered in depth in the diamond mines; and still farther east another extensive stretch of the crystalline basement rocks comes to the surface in Natal and Swaziland. There is growing evidence suggesting that more than one major cycle of sedimentation is represented in this great assemblage, but everywhere the last event appears to have been the intrusion of pegmatites. In the neighbourhood of the Witwatersrand area the crystalline rocks are older than those of the Witwatersrand system and it is commonly believed that the whole of this Basal Complex is of pre-Witwatersrand age.

Tectonic considerations make this generalisation highly probable, but it must be clearly realised that in Gordonia as in Swaziland, no visual demonstration is possible. In Gordonia pegmatites similar to those containing uraninite are certainly older than the Nama system and the still older Koras series, both of which rest with strong discordance on the Basal Complex. The Koras volcanics are correlated by South African geologists with those of the Ventersdorp, which followed the Witwatersrand sediments. The evidence favouring a pre-Witwatersrand age for the Gordonia pegmatites thus lies partly in this correlation and partly on the fact that there is little discordance between the Ventersdorp and the Witwatersrand, whereas the unconformity between the Koras and the Gordonia Complex is of the strongest type, like that at the base of the Witwatersrand.

In Southwest Africa Gevers (1932, p. 17) has subdivided the Complex and the overlying rocks as follows:

Nama System

- Konkip system
  - Auborus Series
  - Sinclair series
  - Kunjas series

Pegmatites and Granites
Phyllite and Chlorite-Schist formations

Older Gneissose Granites

- Damara system
  - Khomas series
  - Marble series
  - Chuos tillite
  - Quartzite series

Pre-Damana Gneiss
Abbabis system

The Kunjas series has been correlated by Beetz (1929) with the Witwatersrand sediments, and the overlying Sinclair lavas with the Koras and Ventersdorp lavas. A tillite at the base of the Kunjas series is probably the equivalent of the tillite in the Government Reef series of the Witwatersrand and the Numees tillite of Namaqualand. The youngest rocks of the worn-down floor on which the Konkip series lies are pegmatites, which appear to belong to the same group as those of Gordonia. In a later paper on Southwest Angolia, Beetz (1933) correlates the Konkip system and the underlying phyllites and chlorite-schists with the Muva-Ankole system of Central Africa. He points out that the Chella granite of Angola cuts the lower formations, but not the younger unconformable group which is equivalent to the Konkip.

Turning now to Central Africa, we find a widespread sequence that makes it possible to suggest an upper limit for the Witwatersrand and Transvaal systems. In Northern Rhodesia and Katanga (Jackson, 1933, p. 50, and Barnard, 1931, p. 210) the correlated successions are:

Northern Rhodesia	Katanga
Mineralisation	Mineralisation
N'Changa Younger Red Granite	Granites, diorites, and gabbros
Younger Grey Granites	
Kundelungu series* Bwana M'Kubwa series	Katanga System
N'Changa Older Red Granite	
M'Kushi and Muliashi Gneiss	
Muva system	Muva system
Basement Schist Series	Archæan Complex

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* It is possible that only the Lower part of the Kundelungu series is older than the granites and mineralisation.

At the meeting of the South Equatorial Section of the African Geological Surveys held at Kigoma in 1931 (Proceedings, 1932, p. 28) the following correlation was adopted:

South Africa	South Equatorial Africa	
Waterberg system	Upper Kundelungu	Katanga system
Transvaal system	Lower Kundelungu Mines series	
?Ventersdorp system in part Witwatersrand system ?Primitive system in part	Muva-Ankole system	
Swaziland system in part	Basement Complex	

The age of the Transvaal system and its probable equivalents, the Lomagundi system in Southern Rhodesia, the Katanga system in Central Africa, the Nama system in South West Africa, and the Malmsbury series of the Cape Province, has been long disputed, some authors having advocated a Lower Palaezoic age and others a late pre-Cambrian age. So far as the Katanga system is concerned, however, a pre-Cambrian age is clearly indicated by the lead-ratios of the Katanga pitchblende. The average of a long and accordant set of ratios is 0.08 (see Holmes, 1931, pp. 363-367), corresponding to an age of 600 million years. The base of the Cambrian cannot be placed much beyond 500 million years (Holmes, 1933, p. 182).

The correlation of the Katanga with the Transvaal and Nama systems is one of the most convincing of all the lithological correlations of Africa. If it be accepted, then the Upper pre-Cambrian formations of Africa fall naturally into two well-marked cycles of sedimentation each of which is followed by igneous activity and earth movements of varying degrees of intensity according to the locality. In South West Africa the two cycles are represented by the Konkip and Nama systems; in the Transvaal by the Witwatersrand-Ventersdorp and Transvaal systems; and in south equatorial Africa by the Muva-Ankole and Katanga systems.

While we may now feel reasonably confident about the position of the Witwatersrand and Katanga systems, there still remains a doubt concerning the pre-Cambrian age of the Nama system. Haughton's recent discovery in the latter of organic remains which he refers to the Archaeocyathinae suggests, though not conclusively, a Cambrian age for the Nama. Gürich has also found fossils in the Nama, but they are of no value for dating the beds (1930, p. 670). If the Transvaal

System is equivalent to the Nama, then it remains uncertain whether it is Cambrian or late pre-Cambrian. If, however, the Transvaal is equivalent to the Katanga, it is certainly pre-Cambrian. More than this cannot, unfortunately, be said at the moment, but work is now in progress on the age of the Bushveld norites that should settle the question for the Transvaal System.

In conclusion I wish to express my thanks to Dr. A. L. du Toit, Dr. A. Rogers, and Mr. E. D. Mountain for their help in providing information not otherwise available, and to Dr. F. Hecht for undertaking the analysis of the specimens provided by my late friend, Dr. P. Wagner.

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THE GRANITES AND RELATED INTRUSIVES OF WESTERN CONNECTICUT.*

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Granites, granite gneisses, and related intrusives underlie a considerable part of western Connecticut. They occur as dikes, sills, and larger intrusives whose form and boundaries are obscured by the ever-present glacial till. They also, together with their associated pegmatites, inject and impregnate the more ancient formations to a marked degree. The origin of the individual components of the resulting complex is usually difficult to determine, but the volume of salic intrusives distributed throughout the gneisses of mixed origin is very great.

A number[1] of other writers have described these rocks in the past. Dale and Gregory studied the structures exhibited in quarry openings and gave petrographic descriptions of the rocks, but neither this nor any other publication goes far into the question of their origin.

In 1929,[2] the writer discussed the origin of a number of these formations and in 1933[3] wrote on the effect of the granite that penetrates the composite gneiss known as the Danbury granodiorite gneiss.

Since the first of these papers was written considerable field work and microscopic study have revealed more concerning the character and origin of these formations, so that it appears advisable to discuss them more fully.

The purpose of this paper is to describe those intrusives that can be recognized as separate units and to discuss their distribution and relative importance in penetrating and altering the older schists and gneisses.

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[1] See especially: Manual of the Geology of Connecticut, by W. M. Rice and H. E. Gregory, Conn. Geol. and Nat. Hist. Survey, Bull. 6, 1906. The Lithology of Connecticut, by J. Barrell and G. F. Loughlin, Conn. Geol. and Nat. Hist. Survey, Bull. 13, 1910. The Granites of Connecticut, by T. N. Dale and H. E. Gregory, U. S. G. S. Bull. 484, 1911. The Geology of Massachusetts and Rhode Island, by B. K. Emerson, U. S. G. S. Bull. 597, 1917.

[2] Proposed Subdivision of the Becket Gneiss . . . This Journal, 17, 197-238.

[3] Note on the Danbury Granodiorite Gneiss of Connecticut, this Journal, 25, 1-19.

Figure No. 1 shows the distribution of the chief intrusives and, through the use of blended patterns, indicates the writer's interpretation of the distribution of the mixed types.

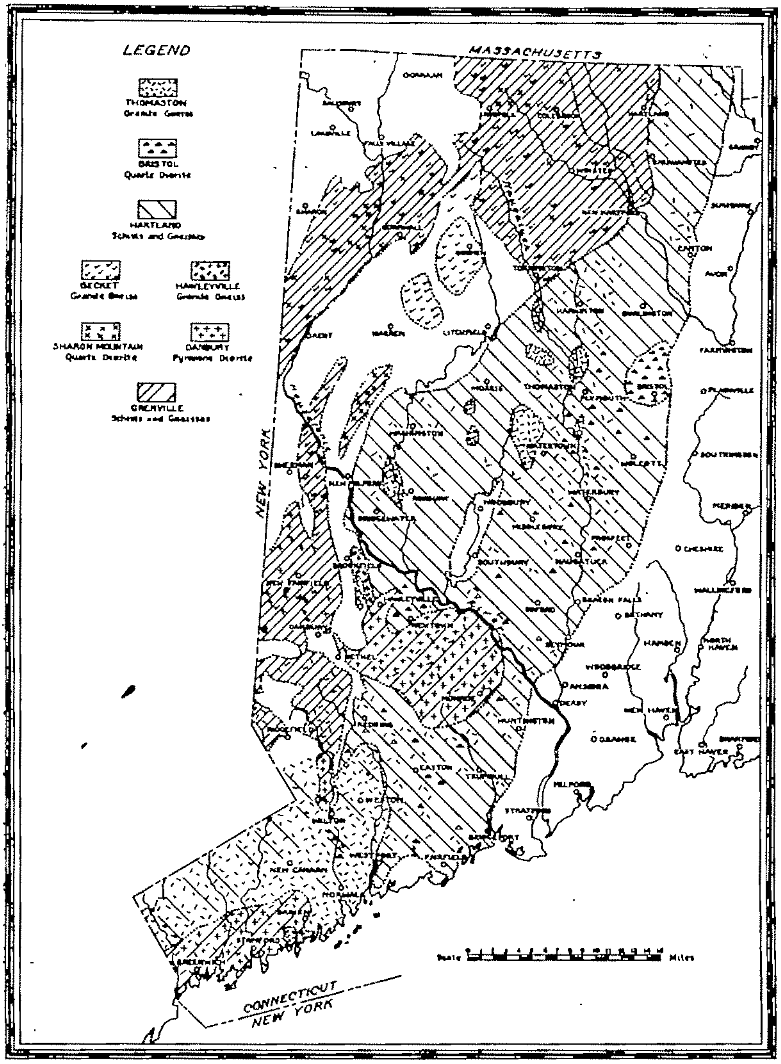

Fig. 1

It will be obvious to the reader that some doubt remains concerning the individuality of the impregnating magma in many of the mixed gneisses. Similarly there are certain of the intrusives that are difficult to allocate to one or the other of the types chosen. This is inevitable in so broad a region. It might result from the existence of many more primary types than are now recognized, or it might be explained through variations in the magmas and magmatic extracts from place to place, as well as in the composition of the invaded rocks, and the tectonic history of the area.

The latter explanation is the one accepted by the writer. The difficulty in allocating a variation to the proper parent type is fully recognized. But, once it is assumed that these varieties constitute intrusives of separate age and history, the types multiply beyond all reason.

Unfortunately there is little definite knowledge concerning the relative age of the invaded rocks. It was the writer's hope that a careful study of the intrusives would enable him to recognize isolated occurrences of each type and help form a basis for the subdivision of the schists according to the number and character of the igneous rocks that penetrate them. This expectation has not been wholly fulfilled, but the following descriptions and discussions are presented with the feeling that they will materially assist in the final elucidation of the problems of age relationship, and because of the necessity of a more accurate statement of the characters and origin of the intrusives themselves.

The Becket Granite Gneiss.

The writer[4] previously restricted the application of the name Becket to the fine, even-grained, gneissoid rock of the Grissey quarry north of Norfolk, Connecticut, thus excluding most of the great variety of gneisses so designated in the Manual of the Geology of Connecticut[5] and on the Preliminary Geological Map of Connecticut.[6]

This rock is a protoclastic biotite granite gneiss unusually rich in oligoclase and extensively altered by albite-oligoclase and quartz.

It was previously called a quartz monzonite gneiss (see reference 4) but, because of the biotite and the sodic character of the plagioclase it is thought best to use the name granite even though the amount of oligoclase is sometimes equal to that of microcline.

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[4] This Journal, 17, op. cit., p. 219, 1929.

[5] Rice and Gregory, Conn. Geol. and Nat. Hist. Survey, Bull. 6, 1906.

[6] Gregory and Robinson, Conn. Geol. and Nat. Hist. Survey, Bull. 7, 1907.

The enrichment in albite-oligoclase and quartz after the major deformation of the rock is its most notable feature (Fig. 2). This serves to distinguish it from the other intrusives of the region and can be seen both in the relatively pure rock and in the injection gneisses of which it forms a part.

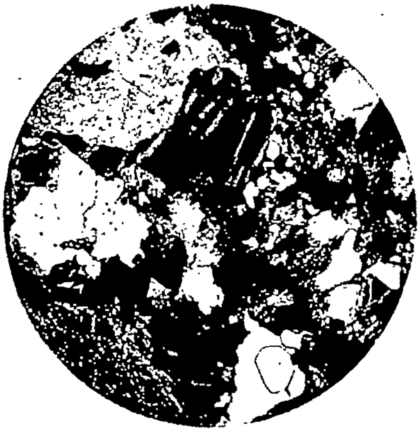

Fig. 2. Becket granite gneiss, from Crissey Quarry, Norfolk. Shows microcline penetrated by myrmekite; oligoclase holding sericite, epidote, and clinozoisite; clear, strained, quartz; and vermicular intergrowths of oligoclase and muscovite. The fine-grained area in the upper right-hand portion is quartz and soda plagioclase with remnants of microcline. Crossed nicols, x 40.

Other distinctive features are vermicular intergrowths of muscovite and oligoclase or quartz, allanite, both epidote and clinozoisite as crystals not directly associated with altered plagioclase, and the color of the biotite.

The minerals and structures are discussed more fully below:

Quartz—This mineral is usually segregated into nests or forms elongated areas composed of individual grains as much as 1 mm. long. Nearly all the quartz exhibits strain shadows and it is sometimes broken into grains averaging 1/4 mm. in diameter with interlocking or sutured boundaries. Aligned liquid or solid inclusions are frequently seen, but are not characteristic.

Quartz also occurs as rounded grains inclosed within microcline and oligoclase and it sometimes clearly replaces microcline.[7]

It is probable that the apparent inclusions of microcline are of this nature.

It also forms intergrowths with sodic plagioclase which are typical myrmekite that grades into more angular patterns simulating micrographic intergrowths but undoubtedly also of replacement origin.

Soda-Microcline—This feldspar has a coarse, interrupted grid-structure and a variable content of microperthitic intergrowths which, however, are sometimes totally lacking. Much of the microcline is strained and some shows peripheral granulation with fragments much smaller than those of quartz. It contains rounded areas of quartz which have replaced it, and inclusions of altered, rounded oligoclase. These are usually completely sericitized.

Microcline is in large part penetrated by myrmekite composed of quartz and soda plagioclase in the albite-oligoclase range. This always embays the microcline. It projects in from the boundaries or forms rounded masses in the body of the microcline, which doubtless projects in from a boundary above or below the plane of the section, or constitutes a fringe along one border. The myrmekite need not project in from a bordering crystal of oligoclase but it frequently does.

Many granular areas of microcline that appear at first glance to be the result of crushing are mixed with a fine intergrowth of albite-oligoclase and sometimes quartz. The granular zones are rarely composed simply of crushed fragments of the mineral that they border but exhibit phenomena of replacement. This is a type of "chemical granulation" as described by Sederholm[8] and noted by the writer[9] in the Danbury region of Connecticut. The granulated zones between the minerals largely controlled the localization of replacement.

Oligoclase—occurs as subhedral to anhedral crystals with a maximum length of 1.5 mm., and as much smaller, rounded inclusions in microcline. It is usually subordinate to microcline but occasionally equals or exceeds it in quantity. Sometimes the center of a large crystal is partly sericitized and this core is surrounded by clear plagioclase with identical index of refraction. More commonly the mineral is irregularly sericitized and contains scattered grains of epidote and clinozoisite with sometimes considerable carbonate. The latter is very irregularly developed.

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[7] See photograph, No. 17, Agar, op. cit., p. 220, 1929.

[8] On Migmatites and Associated Rocks, Pt. II, Bull. de la Commission de Finlande, 77, p. 128, 1926.

[9] This Journal, 25, p. 4, 1933.

Both the irregular and the central alteration of oligoclase are probably the result of a change in composition towards the end of the period of formation, a change too slight to be revealed by index of refraction measurement in thin section. In the first case several, and in the latter case one, early formed crystal was partly altered and then incorporated in a large crystal.

Those small crystals completely surrounded by microcline (in the plane of the section) are more thoroughly sericitized and much less apt to show the beginning of saussuritization than the larger ones. This suggests that the sericitization was coincident with, or at least overlapped on, the period of formation of potash feldspar and that saussuritization, usually poorly developed, came later.

Albite-Oligoclase—the soda plagioclase that enters into the formation of myrmekite and replaces the granulated zones in microcline lies in the albite-oligoclase range. Some is nearly pure albite but most of it is not. It is clear, free from inclusions, and unaltered except where kaolinite has developed in all the feldspars. Careful study of the granular patches mentioned before reveals that the borders of these grains are embayed and intergrown. Some of these may represent myrmekite pulled apart and granulated as it formed, but ordinarily the intergrowth results from infiltration and partial replacement "in situ."

Myrmekite either projects directly from the outer part of an oligoclase crystal or enters microcline from a contact with quartz or another microcline crystal.

Biotite—The biotite is characteristically dark, greenish brown, and nearly opaque parallel to the basal cleavage, and light straw yellow in the direction of the fast ray. It is the dominant mafic mineral and forms sharp laths as well as irregular crystals. It is usually primary, though the anhedral forms probably developed late and the frequent ragged, dactylic borders seem to have been added to the earlier crystals when the myrmekite was formed. There are, however, no typical biotite-quartz-symplektites penetrating the myrmekite, such as are described by Sederholm.[10]

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[10] On Synantectic Minerals, Bull. de la Comm. Geol. de Finlande, No. 48, 1916.

Pleochroic halos around zircon, probably also around allanite, and indeterminable specks are present in considerable quantity, but they are not a particularly notable or necessary feature of the mineral. Chlorite, with a low grey birefringence and a bright green color, replaces some biotite along cleavage lines. Flakes cut parallel to the cleavage may appear to be fresh or completely altered. Individual flakes commonly have a parallel or sub-parallel orientation and are lined up in zones with the accessory minerals and some muscovite to give the rock a rough foliation.

Muscovite—is sometimes an important mineral though rarely as prominent as biotite. It forms many complicated myrmekite—like intergrowths with oligoclase and sometimes with quartz. Some features suggest that this is a primary intergrowth. For instance, it spreads out as a vermicular growth in primary oligoclase, and sharp laths of muscovite occurring with biotite in the foliae of the rock may end in these fine intergrowths. On the other hand, its vermiform, myrmekite-like structure seems to prove a replacement origin. It is so regarded here. The writer believes that it formed either at the late stage in the primary crystallization when microcline formed, or when myrmekitization freed quantities of potash from the corroded and replaced microcline. The fact that movements continued to effect the magma at least up to the time immediately following the crystallization of microcline, and that muscovite has been aligned by this movement suggests the earlier period of formation.

Muscovite as definite, sharp crystals also occurs together with sericite in the sericitized oligoclase. This is an alteration that indicates a relatively elevated temperature at the time when it occurred.

Epidote Group—Epidote, clinozoisite, and allanite all occur in the rock. Epidote and clinozoisite have two modes of occurrence. (1) as isolated grains or groups of minute needles and grains not aggregated into recognizable crystals. (2) as subhedral or anhedral crystals that may be ¼ mm. in diameter. These are evenly distributed throughout the rock or, more often, aggregated with biotite and the accessories along the bands of mafic minerals.

These two minerals are frequently intergrown and often surround a brownish core of allanite. The rim of epidote may be a single crystal, a group of grains or an aggregate of minute rods and grains.

Allanite is regarded as a primary accessory mineral. Epidote and clinozoisite are in part alteration products of plagioclase and in part of uncertain origin. They occur in the same manner as the accessory minerals, are in bands with them, and appear to have the same origin. They may be late hydrothermal minerals, their commonly accepted origin, but there is no indication of such an origin here.

Accessory Minerals—Apatite, both euhedral, and as larger anhedra with dark inclusions, and magnetite, are constant accessories. Titanite is sometimes present in large quantity, more often, it is entirely lacking. When present it is partly leucoxenized. Zircon usually forms recognizable grains in biotite and may occur as small anhedral crystals in any of the other minerals.

These descriptions show that the Becket in its present form is the result of the replacement of a biotite granite, unusually rich in oligoclase, by sodic and siliceous concentrates. Previous to this alteration the primary oligoclase became unstable and was replaced by the potash-bearing sericite, and during one of these periods of alteration large crystals of muscovite penetrated the oligoclase in myrmekite-like forms, chlorite was developed in the biotite, leucoxene in the titanite, and epidote and clinozoisite in the oligoclase.

Interpretation of the structure of this rock is doubly difficult. The replacement that simulates a granulation masks the actual result of crushing. However, the alignment of biotite and the accessories together with some bending and crushing, and the distribution of some microcline show that actual mechanical deformation did take place.

The existence of delicate myrmekite growths and the slight crushing of the quartz indicate that they formed later. This is the basis for applying the term protoclastic to the rock.

But another factor must be taken into account. The types chosen to represent the Becket and previously described, twenty-two in all, represent but a small part of the rock. They are selected samples judged to be nearly free from admixed country rock. These grade in all directions into banded gneisses with the Becket as one of the components. This type of occurrence is the dominant one and the gneissoid structure is largely inherited and to a less extent due to crushing before the late-stage addition of albite-oligoclase and quartz. For this reason the possibility of an inherited structure in the apparently pure Becket cannot be overlooked. There are all gradations between the two, and the content of titanite and altered oligoclase very clearly rises in those examples of the Becket granite gneiss that have schist remnants in them. The strongly banded mixed gneisses contain much more biotite, epidote, titanite, and occasionally hornblende, but these minerals are segregated into folia in the same way as in the Becket itself, and the mafic streaks are separated by bands of myrmekitized microcline, altered oligoclase, and quartz.

The writer previously[11] called the most granitic type of this latter rock the Barack Mountain granite gneiss and regarded it as an older intrusive forming the igneous component of the widespread mixed gneiss series. He has abandoned that view at the present and regards the Becket magma as a widespread impregnating agent.

The occurrences of the Becket as previously described are as follows: The Crissey quarry on Ball Mountain north of Norfolk. A series of railroad cuts along the old line at West Norfolk. Many localities south and east of Norfolk such as Dutton Mountain, Pine Mountain and south and east from these to Torrington and Winsted. Cobble Hill at South Canaan, Barrack Mountain south of Falls Village and the continuation of this range southwest to Sharon and south to Cornwall. White Rocks in Cornwall Village and some new road cuts in that region furnish excellent examples. West of Housatonic River the gneiss range extends south to Bulls Bridge and isolated ridges repeat it east of the river from south of Lake Waramaug to the Danbury region. Many dikes and sill-like intrusions occur in this broad region intrusive into the widespread gneisses and schists. It is possible that there are examples of the typical Becket south of Danbury, but the writer does not yet know of them.

The major part of the rock of all of this area is of mixed character and as will be noted beyond, the Becket is the youngest but not the only igneous rock that has penetrated the older metamorphic rocks.

South of Mohawk Mt. in Cornwall and around Tyler Pond in Goshen there are two granite areas of considerable extent whose boundaries are everywhere completely hidden. The granites underlie the topographic lows and are surrounded by higher areas of schist and gneiss intruded by dikes of granite. Scattered flat glaciated outcrops enable one to determine the general character of the granite. It is a medium-grained whitish rock with all of the characteristics previously described as diagnostic of the Becket. Biotite, however, is variable in its character. Some of it has a dark green-brown color and relatively few halos, but some is reddish brown and full of halos—this is more characteristic of the Thomaston granite.

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[11] This Journal, 17, p. 211, 1929.

These granites are intruded into coarse biotite, sillimanite, garnet, and staurolite-bearing schists irregularly mingled with amphibole gneisses. This series has been mapped[12] as Berkshire schist and the granite as Thomaston. For the reasons stated above the writer now considers that the granite is the Becket granite, but reserves judgment concerning the schists.

North of the granite mass at Tyler Pond, between it and Cornwall Hollow, dikes that represent the Becket as truly as does the rock of Norfolk intrude a coarse biotite schist. Just west of Norfolk on the road to Wangum Lake a similar dike cuts the coarse-grained schist of that region.

The Thomaston Granite Gneiss.

The Thomaston is a fine to medium-grained bluish grey or white rock that has massive phases but is usually distinctly gneissoid. The dike at Reynold's Bridge near Thomaston, in which two quarries have been worked, is a white, fine-grained, massive variant with an unusually high content of sodic oligoclase. Another similar looking, but smaller dike, shows in a roadcut just west of Terryville on the road between Thomaston and Bristol. This rock is slightly gneissoid and contains the normal marked excess of microcline over oligoclase.

The minerals that compose the Thomaston are described below.

Quartz—occurs as relatively large grains that are always somewhat strained and sometimes show incipient granulation. It is always anhedral and characteristically holds minute alined inclusions.

Microcline—is fresh and very rarely penetrated by myrmekite-like growths of quartz and oligoclase. These have more the form of micropegmatitic intergrowths, than that of true myrmekite, but are believed to be formed by replacement. Many thin sections show none at all and it is never important. Microcline sometimes includes rounded areas of quartz and, in the more gneissoid types, altered subhedrons, or irregular patches, of oligoclase.

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[12] Op. cit., Conn. Survey Bull. 7, 1907.

Oligoclase.—The plagioclase is usually oligoclase near the sodic end of its range. Some is oligoclase-albite. Oligoclase is rarely clear. Sometimes it is only sericitized, but it frequently holds both finely divided sericite and unoriented laths of muscovite from ⅛ to ¼ mm. long, and sometimes tiny grains and rods that are probably epidote (Fig. 3).

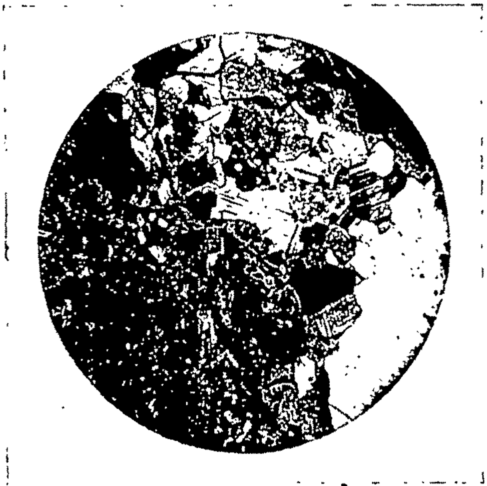

Fig. 3. Thomaston granite gneiss, from small quarry on Ridgefield road just west of Branchville. Shows greatly altered oligoclase-dark and full of sericite, epidote, and fine laths of muscovite; also rounded altered oligoclase in clear quartz and microcline. Crossed nicols, 40.

Some of the massive types of the Thomaston contain oligoclase which surrounds sericitized cores of plagioclase which, when its index of refraction can be determined, is the same as the oligoclase of the rim (Figs. 4 and 5).

Biotite—the two micas, biotite and muscovite, usually occur in considerable amount. Rarely, biotite is the only primary mica. It always has a red-brown color, is strongly pleochroic, and contains many pleochroic halos surrounding small specks. These are sometimes zircon but more often they are indeterminable. Much biotite is partly chloritized and in one belt of gneisses described further on, it is also bleached. The altered parts show a well-developed sagenite structure.

Muscovite—occurs as a primary mineral which sometimes has a tendency to form vermicular growths with oligoclase, but that is not a prominent feature of this rock. Secondary

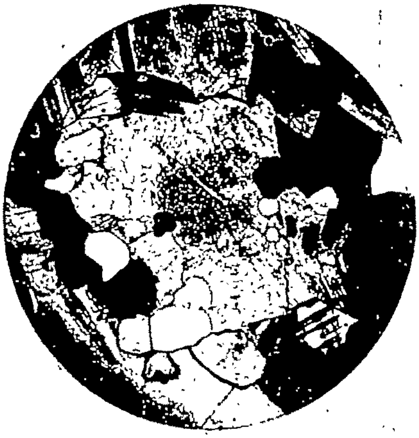

Fig. 4. Thomaston granite from quarry at Reynold's Bridge, Thomaston. Shows plagioclase altered at center to sericite and with a needle of muscovite passing through it; also biotite, muscovite, quartz, and microcline. Crossed nicols, x 40.

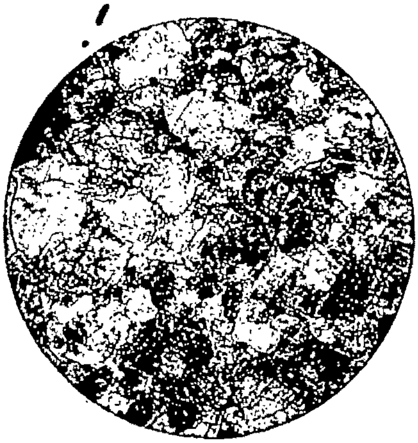

Fig. 5. Thomaston granite gneiss, from road two miles north of Weston. It is composed of clear microcline and quartz, greatly altered plagioclase, and flakes of muscovite and chloritized biotite. Plane polarized light, x 40.

muscovite together with sericite develops in the oligoclase and the gneissoid types contain much secondary muscovite aligned between the other minerals and penetrating all of them to some degree.

Accessory Minerals—apatite is always present in small grains, but is sometimes exceedingly rare. Reddish brown garnet and magnetite are fairly constant accessories. Zircon occurs in biotite and rutile is sometimes present in quartz and in the bleached and chloritized biotite.

It can be seen, therefore, that the type Thomaston is a fresh, nearly unaltered rock. The plagioclase has been altered a little and the biotite slightly chloritized. The prominent late-stage alterations so marked in the Becket are entirely lacking, or at the most, are only incipient. The structure is massive with relatively plain boundaries between the minerals, or gneissoid due to partial recrystallization and the development of new muscovite.

This type of rock is rather widespread but nevertheless is of small areal importance.

It occurs at Reynold's Bridge and as a number of dikes and sills in the region of Thomaston, Plymouth, and Terryville. It is fairly plentiful in the vicinity of Branchville and near Putnam Monument, south of Bethel. It forms dikes and larger intrusions in East Litchfield and Torrington. It forms Mine Hill northwest of Roxbury Station, where it is the country rock of the old Roxbury iron mine—a quartz-siderite vein. It intrudes the diorite that incloses the nickel-bearing, uralitized pyroxenite in West Torrington. It cuts the pre-Cambrian schist on the west side of the valley of the East Branch of Farmington River. The same intrusive occurs as far south as Long Island Sound, where it intrudes both the Hartland schist and the Danbury gneiss.

Throughout its extent it is accompanied by pegmatite dikes which, in fact, far exceed in quantity the typical fine-grained Thomaston. The pegmatites are featured by large quantities of muscovite, quartz, albite, and either white, flesh-colored, or pink microcline. Garnet and tourmaline are often plentiful and cyanite occurs along the border near the schist.

There are two places where the writer believes that these pegmatites show their genetic relationship to the Thomaston granite. The eastern wall of the small quarry at Reynold's Bridge, adjacent to the east end of the new highway bridge, contains a dike of coarse pegmatite of the type described which grades into the granite on both sides and lies a foot or so from the granite-gneiss contact. A later intrusion would almost certainly have chosen the relatively weak contact plane, rather than the mass of solid granite, and would show more definite boundaries. The other locality is the Branchville quarry in the village of that name, south of Danbury. In this case the pegmatite dike in which the quarry was worked grades in several places into a fine-grained granite which itself shows intrusive contacts against the biotite amphibolite country rock. The contact is marked by a few inches of biotite-apatite rock. The granite is one of the types chosen as the Thomaston, and is clearly related to the pegmatite. The coextension of the range of these two intrusives, granite and pegmatite is another indication of a genetic connection.

The Gneissoid and Mixed Types.

A medium-grained gneissoid type of Thomaston occurs in much greater quantities than the rock just described. It grades into pegmatite and holds large inclusions of schist, which it injects to a marked degree. Many rocks, such as the Danbury "granodiorite gneiss" and parts of the Hartland schist, are intimately penetrated and replaced by quartz and microcline derived from this magma. Large areas north of Westport and South Norwalk are underlain by gneiss composed of the Thomaston mixed with an older schist, probably the Hartland. North of Stamford and Greenwich extensive areas of the Thomaston gneiss separate the Hartland schist from the Manhattan schist of the Long Island Sound region in Westchester County, New York. Over most of this area the Thomaston has an inherited structure and is full of more or less completely impregnated inclusions of schist.

The authors of the Manual of the Geology of Connecticut and of the Preliminary Geological map of Connecticut took this into account and called the more gneissoid varieties of the Hartland, resulting from injections by the Thomaston granite and pegmatites, the Waterbury gneiss. The present writer recognizes this type, but finds a general impregnation of the schist still more widespread.

One and a half miles north of Branchville, on the main road to Danbury there is an outcrop where a medium-grained, pinkish, porphyritic granite cuts a fine-grained garnetiferous quartz-biotite schist. The granite is largely composed of pink microcline that holds sericitized crystals of oligoclase. The rest of the oligoclase is also sericitized and altered to individual crystals of muscovite. This rock is a pseudoporphyry formed by replacement. The intrusion and the process is the same that has caused the porphyritic aspect of much of the Danbury gneiss[13] and is certainly referable to the Thomaston granite.

Pink feldspar is not characteristic of the Thomaston granite or its pegmatites. Nevertheless, there are many dikes and certain areas of mixed gneiss with metacrysts of flesh-colored or pink microcline that are referable to the Thomaston granite.

The gneissoid types of Thomaston granite with an inherited structure, the injection gneisses, and the schists and gneisses permeated by quartz and microcline with or without the development of a porphyritic structure result from a more or less complete magmatic infusion of the inclusions and roof-pendants on the upper border of the magmatic chamber. The granite and pegmatite dikes and sills followed after this partially fused and dissolved mass had cooled and crystallized sufficiently to be relatively rigid.

Pegmatitic Granite Gneiss Near Brookfield.

Sheared and crushed granite gneiss intrudes a biotite schist between Brookfield Station and the Danbury-Newtown road along the border of the limestone lowland. It also forms dikes in the limestone along Conn.-U. S. Route, No. 7, both north and south of Brookfield. The rock grades from white through pale flesh-colored to pink and has pegmatitic facies with tourmaline and garnet that interfinger the granite irregularly. It has a well-developed mortar structure. Both microcline and plagioclase are pulverized on their borders and along irregular planes then penetrate them. These crushed parts contain considerable recrystallized muscovite. The primary muscovite is bent and its folia are spread apart. Biotite is both chloritized and bleached and contains sagenite webs.

The quartz in the rock is often granulated but never pulverized. Garnet, tourmaline, and some late-formed magnetite are cracked but not ground up.

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[13] This was previously referred to as The Danbury granodiorite gneiss. It is a gneiss of mixed origin and the old name is not applicable. See W. M. Agar, op. cit., this Journal, 1933.

This structure can best be described as cataclastic-protoclastic (Fig. 6). It shows that the major crushing took place before the quartz, garnet, and tourmaline were introduced late in the pegmatite stage, and that some crushing followed still later. This intrusion is tentatively related to the Thomaston.

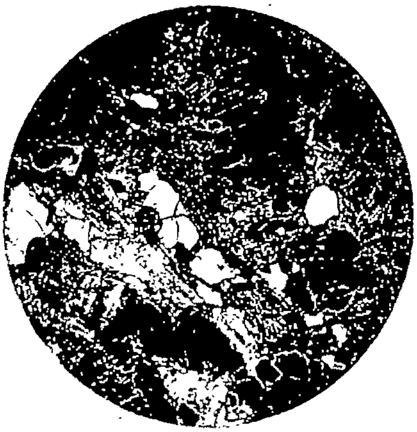

Fig. 6. Sheared Thomaston granite, from Brookfield Junction. Shows feldspar strained and pulverized; much coarser, granulated quartz; chloritized biotite. This is a cataclastic-protoclastic structure. Crossed nicols, x 40.

The Bristol Quartz Diorite.

Granitoid gneisses free from potash feldspar appear repeatedly throughout western Connecticut. Many are undoubtedly biotite-oligoclase paragneisses, but others are unquestionably intrusive into the preexisting rocks and are mixed with them in all degrees of intimacy.

The intrusive at Bristol is a gneissoid, sometimes nearly massive, whitish rock composed of quartz, oligoclase, and biotite with accessory apatite, sometimes zircon and magnetite. It has intruded hornblendic, actinolitic, chloritic, and garnetiferous schists and contains bands that hold these minerals in varying amount. This is chosen as the type of the rock that is roughly coextensive with the Thomaston granite.

The rock in this locality has previously been called the Bristol granite gneiss[14] and described as composed largely of quartz, orthoclase, and oligoclase. The writer has examined a considerable number of thin sections of this intrusive from Bristol and elsewhere, but he has been unable to find any orthoclase. There is much untwinned feldspar, but its indices of refraction are a little higher or a little lower than that of Canada balsam. A sharp, thin edge of a quartz grain almost disappears in this same balsam when turned so that the light is parallel to the slow ray vibration direction. The index of the Canada balsam can therefore scarcely be lower than 1.542 and the feldspar in question is oligoclase. This determination can be checked further by the exact similarity of the indices of the untwinned feldspar and neighboring oligoclase with albite twinning. If orthoclase is present it is a rare accessory mineral.

The same rock occurs just east of Trinity Lake near the Connecticut border in Westchester County, New York. It is here an aplite-like quartz-oligoclase rock nearly devoid of mafic minerals, but it grades laterally into biotite gneiss, which in turn becomes rather typical Thomaston granite gneiss and mixed gneiss through the introduction of quartz and microcline and irregular pegmatitic intrusions.

Near Taunton Hill northeast of Bethel the same mixture of rock types recurs. At this locality, however, the microcline holds rounded, sericitized, grains of oligoclase full of laths of muscovite. Part of the gneiss has a pseudo-porphyritic structure, and microcline is clear and fresh except where peripherally granulated with the development of secondary muscovite. These features are characteristic of the Thomaston granite, yet here the quartz-oligoclase rock, with partly sericitized oligoclase, exists side by side with one that holds microcline and nearly completely altered oligoclase.

At Reynold's Bridge, the dike of monzonitic Thomaston granite already described cross-cuts a coarser oligoclase-quartz-biotite gneiss. This is unlike any of the normal types of Hartland schist and is thought to be a mixed gneiss composed of Bristol quartz diorite and Hartland schist.

It is difficult to know where to place these dioritic intrusives. It was previously stated that a somewhat similar rock is widespread in the Grenville-Becket mixed gneiss area. That was formerly named the Sharon Mountain quartz diorite by the writer[15] and was shown to be older than the Becket granite gneiss, since that rock as well as its pegmatitic derivatives intrude it. The Sharon Mountain quartz diorite carries more biotite than the Bristol rock, as well as epidote, titanite, and occasionally, hornblende. These minerals vary with the composition of the intruded country rock and probably always represent remnants of the older schists, or are formed by reactions with them.

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[14] Lithology of Conn., by Barrell & Loughlin, op. cit., pp. 176-177. Manual of the Geology of Conn., by Rice and Gregory, op. cit., pp. 104-105.

It seems natural to ascribe an essentially similar intrusion in both these areas to one period of igneous activity, but that leads to a difficulty which must be faced. If the same quartz diorite intrudes both the Hartland and the Grenville, why does the Becket granite, younger than the diorite, stop at the border of the Hartland? The writer has found none of the distinctive Becket granite penetrating any of the many phases of the widely extended Hartland schist.

If the Becket and the Thomaston could be regarded as phases of the same intrusion, this difficulty would vanish. But they appear to be quite distinct, so the Bristol quartz diorite must be restricted to the southern and eastern part of the area where the Thomaston granite abounds.

It is probable that these latter two are closely related in age—are in fact, different parts of one magmatic invasion. If an early intrusion, free from potash feldspar, was followed by a quartz-microcline rich fraction, the sericitized and muscovitized plagioclase in so much of the "granite" finds a ready explanation and even the granitoid types of the Thomaston are the result of a double intrusion from an extensive subjacent magma.

This appears more reasonable than to multiply intrusions and best accords with the intimate relationship of the two types. They are, however, separated on the accompanying map in order to indicate the character of the dominant rock in the various regions.

Summary.

The map accompanying this paper (page 355) indicates the relationships between the various formations described. The Danbury gneiss (formerly known as the Danbury granodiorite gneiss) is mapped, even though it is not described here, because it is in part composed of the Thomaston granite. It is shown by the superposition of three symbols—The Grenville, the uralitized pyroxene diorite, and the Thomaston granite.

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[15] Op. cit., this Journal, pp. 216-217, 1929.

This pyroxene diorite in the Danbury region is shown as possibly contemporaneous with the Sharon Mountains quartz diorite. They both intrude schists of supposed Grenville age and are believed to antedate the Hartland schist. They may be varieties of one intrusion, but are shown with different symbols because of their difference in mineralogy.

The Thomaston is divided into two types. The older is a biotite-quartz-oligoclase intrusive called the Bristol quartz diorite. The younger is a microcline-oligoclase granite, the Thomaston granite, relatively free from late-stage effects but possessing great penetrative power and accounting for many of the injection gneisses and mixed types.

The pink phase of the Thomaston occurs largely in the Danbury gneiss area north of New Fairfield but not exclusively there. In fact, no particular local distribution can be assigned to this type, nor is it controlled by assimilation of any particular type of wall rock. Rather it appears to be a product of differentiation of the underlying magma, and is probably a relatively late phase. Certain coarse pegmatites intruding the gneiss along the New York-Connecticut boundary northeast of Ridgebury contain both yellowish white and pink microcline. The pink appears to be later though, at best, there can be but little difference in their ages.

E. S. Moore and G. H. Charlewood[16] consider the evidence for a differentiation origin for the pink phase and the grey border phases of certain granites in Canada. They agree that the grey border phase is more likely to be the result of the separate intrusion of a differentiate than the result of the assimilation of wall rock.

The evidence in this region points to the same conclusion though there is here no definite areal distribution of the two phases.

The Bristol quartz diorite is not considered to be the equivalent of the Sharon Mountain quartz diorite, because the Becket granite gneiss which intrudes the latter is older than (does not intrude) the Hartland schist, which the Bristol rock does intrude.

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[16] Two-granite Batholiths in the Pre-Cambrian, Trans. R. S. C., Sect. IV, 1930.

The Becket granite gneiss is a distinctive type marked by intense late-stage alterations. Its most distinctive features are myrmekitization, vermicular intergrowths of muscovite and oligoclase, sericitized and saussuritized oligoclase, as well as considerable quantity of epidote, chinozoisite, and allanite that shows no evidence of a secondary origin.

There are two other intrusions in western Connecticut which are not considered here. The Brookfield diorite,[17] which is also older than the Thomaston granite and appears to be younger than any of the other formations, and another rack that centers about the Brookfield-Hawleyville region and will be described later.

The superposition of the formations in the legend is based upon their apparent age relationships. No contacts are known between the Hartland and the Grenville, though they lie side by side along the length of the valley of the east branch of Farmington River. But, since the Becket granite cuts the Grenville and is absent from the Hartland, the Grenville is considered to be older. If it were certain that the Hartland is in its original position, this would be valid conclusion, but there remains the possibility that it has been thrust from the east over an unknown distance.

The age of the Thomaston granite as derived from the radioactive minerals in its accompanying pegmatites[18] is late Ordovician. That is the only formation besides the schists and gneisses here called the Grenville[19] whose age is fairly certain, and it is the youngest hard rock formation in the region.

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[17] The Geology of the Shepaug Aqueduct Tunnel, by W. M. Agar, Bull. 40, Conn. Geol. and Nat. Hist. Survey, pp. 28-31, 1927.

[18] Op. cit., W. M. Agar, this Journal, p. 6, 1933.

[19] Op. cit., W. M. Agar, this Journal, pp. 205-211, 1929.

TACONIC, CONNECTICUT.

EURYPTERIDS IN GRAPTOLITE SHALES.

RUDOLF RUEDEMANN.

The recent discovery of eurypterids in graptolite shales, such as the Deep Kill and Snake Hill shales, where they were hitherto unknown, and the discovery of other localities in the Normanskill shale have served to direct attention to the occurrences of eurypterids in New York in general and to the fact that enough species have been described to make the eurypterids an important biotic element of some of the graptolite faunas, especially when it is considered that the typical graptolite shales lack all other classes of organisms. In a recent paper, now in press as a memoir of the Geological Society, the writer has described the graptolites and their associated forms as largely derived from the plankton and pseudoplankton of Paleozoic Sargasso-seas. The eurypterids have there been mentioned but briefly as accidental stragglers that reached the toxic bottom waters where the graptolites came to rest. It appears now that there are altogether too frequent occurrences of the eurypterids in graptolite shales to treat the phenomenon as a negligible, minor incident.

We will therefore here first describe the new forms that have been recently found in graptolite shales of New York, then list the eurypterids so far known from our graptolite shales and finally analyze the facts that give promise of throwing light on the possible original habitat of the eurypterids that were deposited with the graptolites.

1. DESCRIPTIONS OF NEW EURYPTERIDS FROM THE GRAPTOLITE SHALES OF NEW YORK.

Eurypterus hudsonicus nov.

(Figure 1.)

Description. Carapace semioval to broadly subtriangular; widest in posterior fourth of length; length to width as 2:3 (13 mm. and 18 mm.). Lateral margins rounded in posterior portion, contracted toward the posterior margin and converging with nearly straight lines towards the slightly protracted anterior point, forming there a broad blunt angle. Posterior margin with broad depressed border (2.5 mm.); within anterior angle narrow depressed area, forming a snout-like protrusion. Surface of carapace now flattened, originally probably evenly convex. Lateral eyes large (4.6 mm. long), narrowly kidney-shaped, prominent, situated halfway forward and about 1/7 the width from the lateral margin. Median eyes halfway between frontal margins of lateral eyes. No traces of sculpture observable.

Horizon and locality. Ordovician Snake Hill shale at excavation for state dam, in Hudson River, two miles below Mechanicville (R. Ruedemann, coll. 1899). The carapace lies close to a *Hughmilleria kilfoylei* in shale containing *Lasiograptus eucharis*, *Lepidocoleus* and *Triarthrus becki*.

Remarks. *Eurypterus hudsonicus*, although represented by only a carapace, is well characterized by the broad sub-triangular outline of the carapace, the snout-like anterior protrusion and the large lateral eyes. It is in outline similar to *E. chadwicki* Clarke and Ruedemann from the Normanskill shale at Catskill, N. Y., and differs from the latter in the more posterior position of the lateral eyes and the development of the frontal protrusion.

Eusarcus triangulatus Clarke and Ruedemann.

(Figure 2.)

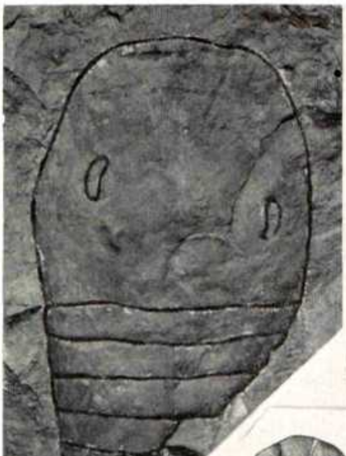
The Snake Hill shale brought out of the Hudson River when the Mechanicville dam was built, was found to contain the carapace and abdomen of an eurypterid larger than most of the Ordovician forms. The outline of the carapace fully agrees with that of the type of *Eusarcus triangulatus*, reproduced in the Eurypterida of New York, pl. 84, fig. 7, and the relative width with that of fig. 9.

The type material of *Eusarcus triangulatus* came from the Schenectady beds at Schenectady. As the Snake Hill beds are contemporaneous, supposed to have been deposited in a more easterly basin, and have many fossils in common with the Schenectady beds, it is not surprising to find this species also in the Snake Hill beds.

Hughmilleria prisca nov.

(Figure 3.)

Description. Body small, lanceolate in general outline. Carapace short, semi-elliptic, length to width as 5:7, widest at base and converging with regularly convex margin to a some-



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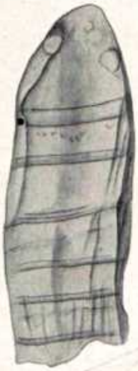

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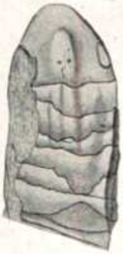

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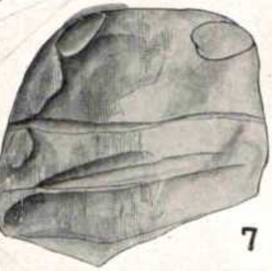

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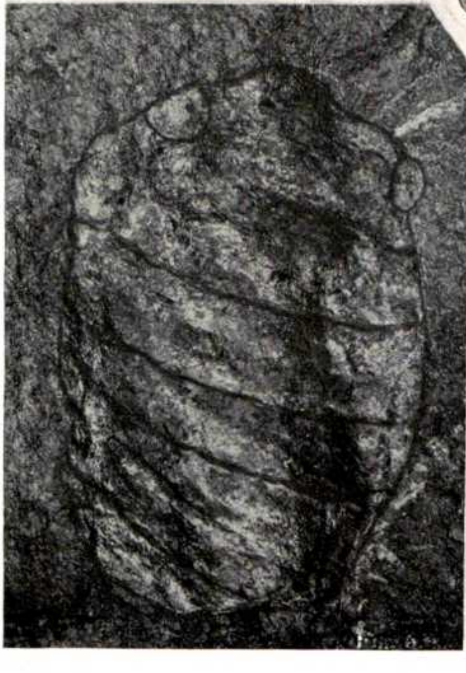

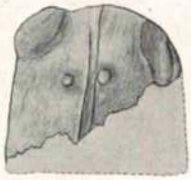

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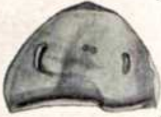

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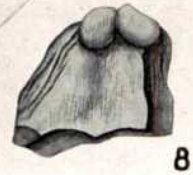

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what narrowly truncated front. Surface of carapace smooth, evenly convex with a broad median elevation reaching 1/3 of the length to the frontal margin. Lateral eyes marginal, located far back, directly behind transversal middle line; about one-third of length of carapace long. Median eyes situated between lateral eyes.

The six tergites are preserved, more or less shoved together and broken. They expanded but slightly in width to the middle of the body, altogether by about one-half the width of the carapace, and possessed considerable length (length to width as 1:3). The traces of the first two postabdominal segments are too poor to permit description. No traces of surface sculpture were observed.

Measurements. The carapace of the holotype is 10 mm. long and 14 mm. wide at the base; lateral eyes 3.5 mm. long. Tergites 4 cm. long and 12 cm. wide.

Horizon and locality. Ordovician Normanskill shale at Glenmont (West Shore railroad cut), N. Y. The specimen is lying on a slab with numerous rhabdosomes of *Diplograptus incisus, Corynoides gracilis* and *Climacograptus parvus* and a *Didymograptus sagittarius.*

Remarks. This interesting eurypterid is the first *Hughmilleria* from the Normanskill shale. It is quite similar to the *H. gracilis* nov. from the Snake Hill shale, but is relatively broader and the eyes are situated more posteriorly.

Fig. 1. Eurypterus hudsonicus Ruedemann. Holotype. Natural size. Ordovician Snake Hill shale at Mechanicville, N. Y.

Fig. 2. Eusarcus triangulatus Clarke and Ruedemann. Plesiotype. Natural size. Ordovician Snake Hill shale at Mechanicville, N. Y. The outlines retouched. The specimen shows distinctly the margins of the tergites, which the photograph has lost.

Fig. 3. Hughmilleria prisca Ruedemann. Holotype. Natural size. Ordovician Normanskill shale at Glenmont, N. Y.

Fig. 4. Hughmilleria kilfoylei Ruedemann. Holotype. Natural size. Ordovician Snake Hill shale at Mechanicville, N. Y.

Figs. 5 and 6. Pterygotus deepkillensis Ruedemann. Holotype and paratype. x 2. Ordovician Deep Kill shale at Deep Kill, near Melrose, N. Y.

Figs. 7 and 8. Pterygotus normanskillensis Clarke and Ruedemann. Plesiotype. Natural size. Ordovician Normanskill shale at Kenwood, N. Y. The original of figure 8 compressed laterally.

Fig. 9. Eurypterus (Stylonurus?) maccarthyi Kjellesvig. Photograph of external mold of holotype. Natural size. Devonian Moscow shale. Ludlowville, N. Y. Originals of figures 1-8 are in the New York State Museum.

Hughmilleria kilfoylei nov.

(Figure 4.)

Description. Body slender. Carapace elongate, semi-elliptic, about as long as wide (probably somewhat laterally compressed, width 15 mm., length 13.5 mm.), widest at base, fairly regularly contracting forward to a more acutely rounded anterior portion. Surface apparently evenly rounded originally. Lateral eyes large (diameter 2.5 mm.), subcircular in outline, little projecting, situated upon or slightly forward of the middle line, marginal, little projecting. Median eyes not seen.

Abdomen of nearly uniform width, not expanding much if any beyond the basal width of the carapace, and of great length; the second and third tergites reaching a length of 9 mm. and a width of 16+ mm. The carapace and the first four tergites have a combined length of 46 mm. Traces of triangular scales are seen on the first tergite.

Horizon and locality. Snake Hill shale at excavation for state dam in Hudson River, two miles below Mechanicville (R. Ruedemann coll. 1899). The specimen lies close to the carapace of *Eurypterus hudsonicus* on slab containing *Lasiograptus* (*Thysanograptus*) *eucharis, Lepidocoleus* and *Triarthrus becki.*

Remarks. Hughmilleria gracilis is comparable in outline to *H. magna*, one of the common forms of the Schenectady shale. As the Snake Hill and Schenectady shales are essentially equivalent formations, the identity of *H. kilfoylei* and *H. magna* is a possibility. Figures 11 and 13 (N. Y. State Mus. Mem. 14, pl. 85) are taken from specimens that present considerable similarity in outline and position of eyes to our form, especially Fig. 11. However, both the carapaces and the abdomen are distinctly broader than in *H. gracilis* and the eyes situated farther forward. In this connection is to be considered the fact that the holotype of *H. kilfoylei* shows distinct signs of having been compressed laterally and obliquely in the longitudinal wrinkles, especially on the right side. It is therefore possible that with more material this form may fall within the boundaries of *H. magna.*

Pterygotus deepkillensis nov.

(Figures 5 and 6.)

Description. Carapace small, subquadrangular in outline, a little longer than wide (l to w about as 11:10); lateral margins nearly straight, very slightly convex and convergent forward. Frontal margins convex, lateral eyes very large (4.5 mm. long), elliptic in outline, prominent, situated at the antero-lateral corners. Median eyes large, situated midway between the posterior margins of the lateral eyes. No sculpture markings were observed.

Horizon and locality. Deep Kill shale at Deep Kill, near Melrose, N. Y., associated with *Goniograptus thureaui* (R. Ruedemann coll. 1901).

Remarks. This species is represented by two specimens, both fragmentary, but the fact that this is the first eurypterid observed in the Deep Kill shale, warrants its description. The subquadratic shape of the carapace and the large prominent lateral eyes will serve as distinguishing characters.

Pterygotus normanskillensis Clarke and Ruedemann.

(Figures 7 and 8.)

Collecting of graptolites by Prof. O. H. Reinholt of Hartwick College, Oneonta, N. Y., at the Normanskill type locality led to the discovery of some eurypterid remains that are worth recording. We are figuring two carapaces that apparently belong to *Pterygotus normanskillensis,* Clarke and Ruedemann, as described from the Normanskill shale at Catskill. The variable compression of the leathery tests has led to manifold appearances.

Fig. 7 is a larger specimen than the holotype. The carapace measures 32 mm. in width and 16 mm. in length. It is quite probable that this head has suffered compression in an anterior direction. Two sternites are preserved, which are also shorter than would seem natural. Each is 7 mm. long.

Fig. 8 is distinctly compressed laterally. It is here reproduced on account of the large size of the lateral eyes, which being placed far forward are pushed together with the right one partly over the left.

Both specimens show distinctly the fine interesting cleavage lines in the thick carbonaceous test, which led to the description of "Rhombodictyon" a supposed sponge, by Whitfield.

II. LIST OF EURYPTERIDS FROM THE NEW YORK GRAPTOLITE SHALES.

Deep Kill shale: Pterygotus deepkillensis Ruedemann.
Normanskill shale:
  a. Catskill: Eurypterus chadwicki Clarke & Ruedemann.
    Eusarcus linguatus C. & R.
    Dolichopterus breviceps C. & R.
    Stylonurus modestus C. & R.
    Pterygotus? (Eusarcus) nasutus C. & R.
    P. normanskillensis C. & R.
  b. Kenwood: Hughmilleria prisca Rued.
    Pterygotus normanskillensis C. & R.
Snake Hill shale: Eurypterus hudsonicus Rued.
    Hughmilleria kilfoylei Rued.
    Eusarcus triangulatus C. & R.
Schenectady beds: Eurypterus? (Dolichopterus?) stellatus C. & R.
    E. pristinus C. & R.
    E. megalops C. & R.
    E.? sp.
    Dolichopterus frankfortensis C. & R.
    D. latifrons C. & R.
    Eusarcus longiceps C. & R.
    E. triangulatus C. & R.
    Stylonurus? limbatus C. & R.
    Hughmilleria magna C. & R.
    Pterygotus prolificus C. & R.
    P. nasutus C. & R.
Utica shale: Echinognathus clevelandi Walcott
    Eurypterus rusti Rued.
    Eusarcus breviceps Rued.
    Dolichopterus insolitus Rued.
    Stylonurus sp.
    Hughmilleria uticana Rued.
    Pterygotus walcotti Rued.

III. MODE OF OCCURRENCE OF THE EURYPTERIDS.

There are altogether 29 different forms of eurypterids recognized in the graptolite shales. While those of the Deep Kill and Snake Hill shale have only been found as single specimens, the faunas of the Normanskill shale at Catskill and of the Schenectady beds at Schenectady consisted of numerous fragments, in some places crowding the surface of the slabs as much as the graptolites. We have a slab from Catskill on exhibition in the Museum, that bears in an area of 6 × 5 inches 2 species of graptolites and 3 species of eurypterids (8 heads and numerous body fragments), thereby demonstrating a strange commingling of the two very different classes of organisms.

The following general observations can be made as to the distribution of the eurypterids in the graptolite shales.

1. The eurypterids found in the pure graptolite shales (Deep Kill, Normanskill), where obviously no bottom fauna could exist in the foul bottom waters, are always very fragmentary. No complete specimens retaining the appendages have been found. The remains consist of carapaces and separate body segments as is readily seen in the illustrations of the Normanskill fauna on pp. 423-417 of the Eurypterids of New York. Only of *Stylonurus modestus* were obtained a few specimens with both carapace and body segments still in contact and one specimen showed part of a walking leg.

2. The eurypterids in the graptolite shale are rarely found in the midst of black mud shale deposits. The few specimens obtained in the Deep Kill shale are in black graptolite-bearing shale, those of the Normanskill shale collected in the Broom street quarry at Catskill, N. Y., rest on a thin black shale layer, with graptolites, that covers a sandy bed, and the Normanskill eurypterids at Kenwood, near Albany, were found on the surface of a grit bed at the boundary between the grit and the black shale.

3. In the Schenectady beds the writer discovered in the bluestone quarries at the outskirts of Schenectady a rich eurypterid fauna that afforded 11 species. The Schenectady beds consist there of barren impure sandstone beds with thin black shale intercalations. The latter contained the mixed fauna of eurypterids, graptolites, brachiopods, mollusks and trilobites listed in 1912 by the writer (1912, pp. 48-49), altogether 38 forms being cited and one, quite common seaweed, *Sphenothallus latifolius* (Hall). The best fairly complete eurypterids were found in the black shale, fragments were also frequently observed on the surface of the sandstone.

4. The Utica shale contains the six species of eurypterids described by the writer (1926) in black shale together with the fairly large mixed Utica fauna, composed of graptolites and a somewhat impoverished aggregation of brachiopods, cephalopods and trilobites. The eurypterids are fairly well preserved, retaining the carapaces and all, or the larger part of the bodies. In one case (see Ruedemann, 1926, plates 27, 28) two specimens, representing two different genera were rolled together into a ball, that was labelled as a seaweed (Discophycus typicale Walcott).

5. The black Snake Hill shale has furnished three specimens belonging to different genera, one a carapace and body, the other a carapace lying close together on a small slab, 2 × 3 inches in size, in association with graptolites, Lepidocoleus, etc., and a large carapace and abdomen of the Schenectady species *Eusarcus triangulatus* C. and R.

IV. MEANING OF THE DIFFERENT MODES OF OCCURRENCE.

It is natural to ask oneself how these very different organisms, the graptolites and eurypterids, happen to come together in the graptolite shales, like immigrants from different countries in a common "melting pot." The graptolites found in these shales are known to have had their habitat in the open ocean, and to have been drifting either as plankton or as epiplankton, attached to the seaweeds of the Paleozoic Sargasso-sea. The eurypterids on the other hand were distinctly bottom-dwellers and mostly mud-grovellers, such as many trilobites were. Their well-developed walking legs and their flattened bodies testify to a walking and swimming life near the bottom.

Grabau and O'Connell (1913) solved the problem easily and ingeniously by placing the eurypterids in the rivers, whence they drifted into the deltas, while the graptolites were thrown and stranded upon the same deltas by storms. The writer has often wished that this view would solve the problem. However, there are constantly arising difficulties that caution against a too ready acceptance of Grabau's and O'Connell's hypothesis. They placed their main argument for the river habitat of the eurypterids on the occurrences in the Bertie waterlime. The latter has been shown by the writer (1925, p. 9) to be marine and a deposit in lagoons behind coral reefs, with a fairly large truly marine fauna (some forty species). The often large eurypterids occur there in such perfection, together with very young growth-stages, that they could not have been transported far.

The same is true of the Pittsford shale fauna with its beautifully preserved specimens, found in black shale together with lingulas and other brachiopods. On some slabs the eurypterids occur in great profusion and perfection, as on a slab with *Hughmilleria socialis* in the State Museum.

These Silurian faunas show no graptolite association, or only sessile *Dendroidea* (the Bertie waterlime contains three species of Dendroidea and a minute planktonic graptolite, *Climacograptus ultimus*; the Pittsford shale not any graptolites). Yet planktonic graptolites (*Monograptus*, *Retiolites*) entered the Silurian sea of Western New York in multitudes at the time when the Williamson shale was deposited, and the presence of the small *Climacograptus ultimus* in a single layer shows also a temporary connection of the lagoon with the open sea.

The third case of a large Silurian eurypterid fauna lacking association with graptolites is that of the Shawangunk grit fauna discovered by the writer at Otisville, N. Y. As in the Schenectady beds we have here a thick formation composed of alternating sandstone and shale; in the Shawangunk grit thin layers of black shale filled with mostly fragmentary eurypterids, but lacking all other fossils. The grit has furnished a few specimens of eurypterids and some fish remains. A single *Lingula* on black shale is in the State Museum. The Shawangunk grit is currently considered by stratigraphers as a delta deposit. Assuming that this view is correct, the Shawangunk grit beds would, on account of their very regular alternation of grit and shale, less probably represent the topset beds than the bottomset or foreset beds. If they represent the marine end of the delta, marine fossils except the eurypterids should be found, especially also graptolites. Their lack would seem to support Grabau's view that the eurypterids represent the river fauna and were brought down by the river into the delta. Against this view stands the fact of the occurrence of numerous small growth-stages of all genera, down to 1 mm. in size (see Memoir 14) which prove that the eurypterids must have been living and breeding in that neighborhood. It is therefore our conviction that like their recent relative, the *Limulus*, they came from the deeper sea to the shore and deposited their eggs in the sand of the littoral zone. The graptolites did not reach the interior of this early Silurian epicontinental sea at all because no ocean currents entered it.

The Bertie waterlime, Pittsford shale and Shawangunk grit occurrences of eurypterids, the most important and perfect faunas of our Silurian, leave no doubt that eurypterids and graptolites were not associated in the same habitat. The same conclusion is suggested by the faunas of the Normanskill and Schenectady beds, for in the Normanskill shale they occur only in a single layer on top of or close above a sandstone bed and in the Schenectady beds they are found both in the shale and the sandstone. The other finds, those in the Deep Kill and Snake Hill shales, are only occurrences of one or two specimens and serve but to support the view of their accidental commingling with the graptolites. It is here also significant that the foreign graptolite shales have never afforded any eurypterids and that normally eurypterids and graptolites are not associated. This relegates them from the marine plankton.

As the Ordovician and Silurian eurypterids, with which alone we are here concerned, were undoubtedly marine in habitat, there remains the nektonic life near the bottom and the vagrant benthonic life on the bottom of the sea. The extreme rarity of the eurypterids in the black shales of the pure graptolite shales (Deep Kill shale and Normanskill shale) and their more frequent occurrence near the sandstone beds, as well as in the mixed graptolite faunas (Utica shale) suggest that they lived in the littoral, or higher neritic zone, perhaps like Limulus wandering up and down seasonally, and that thereby they were liable to be carried into the quiet dead and toxic bottoms where the graptolites were deposited, by the same agencies, extreme storms or tidal currents, that brought the sand into these deeper levels and that wrecked the graptolite colonies that gradually settled with the seaweeds, the black shale forming mainly from the wreckage after the storms subsided.

Many of the eurypterid remains were undoubtedly the leathery integuments shed after moulting. Clearly moulted tests, split open at the front were observed by the writer (see Clarke and Ruedemann, pl. 6, fig. 1) in the Bertie waterlime, and the dismembered fragments have all the appearance of residues from moulting. Likewise the rolled up group of specimens observed in the Utica shale suggests transportation of light moulted skins rather than the heavier carcasses on the muddy bottom where only the weakest of currents, if any, prevailed. It is then very probable that these light exoskeletons were more easily transported than the shells of the associated benthonic life and thus appeared alone when the storms and currents that moved the sand subsided and black mud deposition began again. This happened hundreds of times in repetition in the Shawangunk sea and similarly in the Schenectady sea. We consider it even very probable that many of these light skin-fragments floated in the water and did not come to rest at the bottom until complete quietude was restored. To reach the deep toxic waters where the Deep Kill graptolites were deposited they had to float out much farther than in the case

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Professor Sven Oden, the Swedish chemist, died on January 16 in his forty-seventh year.

Dr. Harry D. Campbell, professor of geology in the faculty of Washington and Lee University for 47 years, and dean for 26 years; died at his home in Lexington, Virginia, on April 10 in his 72d year.

PUBLICATIONS RECENTLY RECEIVED.

Les Ressources minérales de la France d'outre-Mer. I. Le Charbon. II. Le Fer, Le Manganèse, Le Chrome, etc. Paris, 1934. Société D'Editions Géographiques, Maritimes et Coloniales.

Papers Concerning the Palaeontology of California, Arizona, and Idaho. Carnegie Institution of Washington, 1934.

Actualités Scientifiques et Industrielles. 78. Le Devenir du Sexe par Vera Dantchakoff, 15 frs. Paris, 1933. 95 Dysharmonies et Discontinuités, by Georges Teissier, 10 frs. 100. Polarisation et Dépolarisation Cellulaires par M. Dubuisson, 12 frs. 101. Les Pagures ou Bernards L'Ermite par Charles Pérez, 9 frs. 102. Transporteurs D'Oxygène par Marcel Florkin, 12 frs. 103. Adaptation Ecologie et Biocenotique par Marcel Prenant, 15 frs. 106. La Cellule et les Protozoaires par Georges Bohn, 18 frs. 120. II. Reproduction Sexualité Hérédité par Georges Bohn, 15 frs. Paris, 1934 (Hermann & Cie).

The Thermodynamics of Electrical Phenomena in Metals; by P. W. Bridgman. New York, 1934 (Macmillan Company, $3.75).

Resonance Radiation and Excited Atoms; by Allan C. Mitchell and Mark W. Zemansky. (Cambridge: At the University Press, 1934. New York: The Macmillan Co., $5.00.)

Carnegie Institution of Washington. News Service Bulletin Vol. III, No. 15. Some Characteristics of Tumor Cells.

Ventilation. A Text-book for Students and Engineers; by E. L. Joselin. London, Edward Arnold & Co. New York, 1934, Longmans, Green & Co.

Outlines of Physical Geology; by Chester R. Longwell, Adolph Knopf, Richard F. Flint. New York, 1934 (John Wiley & Sons, $3.00).

A Manual of Thesis-Writing for Graduates and Undergraduates, by Arthur H. Cole and Karl W. Bigelow. New York, 1934 (John Wiley & Sons, $.75).

The Design and Use of Instruments and Accurate Mechanism; T. N. Whitehead. New York, 1934 (The Macmillan Co., $3.50).

The Snellius-Expedition in the Eastern Part of the Netherlands East-Indies, 1929-1930. Vol. V. Geological Results. Part 2, Geology of Coral Reefs; by H. Kuenen. (Kemink En Zoon N.V. Utrecht.)

Charters and Basic Laws of Selected American Universities and Colleges; by E. C. Elliott and M. M. Chambers. Pp. vii, 640. New York, 1934. Carnegie Foundation of the Advancement of Teaching, 522 Fifth Ave.—Fifty-one institutions are mentioned. They include the Private Corporations chartered: (1) by the Crown of England, (2) by an English Colony, (3) by Congress, (4) by the States. The Public Institutions include one Municipal, and eighteen established by the States.

24 species in their relative sizes. Fifteen pages of bibliography will be appreciated by specialists and teachers. It is to be regretted that the synonymy of species is omitted, but as it is quite extensive and may be found in some of the works listed in the bibliography, the omission is not serious and permits the price to be reasonably low. The authors are to be congratulated on having produced such a useful and fine piece of work. A. PETRUNKEVITCH.

CORRIGENDA.

In the paper by W. C. Krumbein, entitled "The Probable Error of Sampling Sediments for Mechanical Analysis," Vol. 27, March, 1934, the following corrections should be made:

P. 205, line 5, for "is reduced to zero" read "is held constant."

P. 208, line 10, insert "as a variable" at the end of the sentence closing with "include only the laboratory error."

OBITUARY.

DR. ROY LEE MOODIE, the chief authority on Paleopathology, died in Los Angeles on the sixteenth of February at the age of 54 years. A graduate of the University of Kansas he took his doctor's degree at the University of Chicago. His latest work on the Paleopathology of the Rancho la Brea and other Felidae had just been completed at the time of his death. This will be published by the Wellcome Historical Medical Museum with which he was connected.

DR. FRANCIS PRESTON VENABLE, professor of chemistry at the University of North Carolina from 1880 to 1900, 1914 to 1930, also president from 1900 to 1914, died on March 17 at the age of seventy-seven.

DR. ELON HOWARD EATON, the ornithologist, professor of biology at Hobart and William Smith Colleges, died on March 27 at the age of sixty-seven.

MAJOR J. MAKINTOSH BELL, Canadian mining engineer and geologist, died on March 31 at the age of fifty-six years.

DR. WILLIAM BARLOW, the English chemist, known for his work on chemical valency and crystal structure, died on February 28 at the age of eighty-eight.

SIR THOMAS MUIR, the mathematician, superintendent-general of education at the Cape of Good Hope, died recently at the age of eighty-nine.

DR. FRANCIS ARTHUR BATHER, earlier of the geological department in the British Museum, died on March 20 at the age of seventy-one.

DR. OSKAR VON MILLER, founder of the Technical (Deutsches) Museum in Munich, died on April 9 at the age of seventy-eight. He was a pioneer in the use of electricity.

eye, also colored—undoubtedly arose, as the synthetic English-Dutch race is shown to have arisen, by a cross-over between the closely-linked genes English and White-Dutch in an individual heterozygous for both.

Dr. Sawin, in the second paper, presents evidence that two genetic influences are of primary importance in determining eye-color in the rabbit. First, albino allelomorphs determine a graded series of intensity in the coat and in the choroid and retinal epithelium of the eye, and the red glow of the pupil by reflected light in albinotic forms. They also determine a series of stages in decreasing iris pigmentation, parallel with that of coat and retinal color with certain exceptions. Second, independently inherited modifying genes also affect pigmentation of the iris.

The author also points out certain analogies between the inheritance of blue eye in the chinchilla rabbit and in man; and reports a new variation, consisting in an increased width of the agouti band in the fur. S. C. B.

Bumblebees and Their Ways; by OTTO EMIL PLATH, with a Foreword by WILLIAM MORTON WHEELER. Pp. xvi, 201; with 10 pls. and 20 text figs. New York, 1934 (The Macmillan Company, $4.00).—The family lives of these industrious and highly useful insects are revealed by a reliable observer after thirteen years of patient study. The story of their marvelous instinctive behavior during the founding of the colony, rearing the young workers, queens and drones, gathering and storing food, their treatment of uninvited guests, parasites and enemies, and the final disintegration of the colony before the approach of winter is told in a most entertaining manner. An appendix contains a detailed account of the common North American species, including the guest bumblebees, and an extensive bibliography. The nature lover as well as the scientist will enjoy this book. W. R. C.

Handbook of Frogs and Toads. The Frogs and Toads of the United States and Canada; by ANNA ALLEN WRIGHT and ALBERT HAZEN WRIGHT. Ithaca, N. Y., 1933 (The Comstock Publishing Co., $2.50).—This little book is one of a series of Handbooks of American Natural History, edited by Prof. Wright. It is meant to serve as "a guide for teachers, students and even younger naturalists" and should prove to be of great use to everybody interested in learning the distinctive characters and the breeding habits of these animals, some of which in recent years have been used extensively by experimental zoologists and probably will be used still more so in the future. Keys are given to families and species which are easier identified as such, without intermediate keys to genera. Each species is carefully described and illustrated by photographs from life. Line drawings accompany the keys and are very helpful in identification. Very useful also is the plate showing eggs of

No. 138. A Presomite Human Embryo with a definite Chorda Canal; by CHESTER H. HEUSER. Pp. 251-267; 7 pls.—This is a description of what is probably the best representative of this very early phase in the development of man. S. C. B.

Gorillas in a Native Habitat; by HAROLD C. BINGHAM. Report of the joint expedition of 1929-30 of Yale University and Carnegie Institution of Washington for psycho-biological study of the mountain gorillas (*Gorilla beringei*) in Parc National Albert, Belgian Congo, Africa. Pp. 66; 22 pls., 5 figs. Washington, 1932 (Carnegie Institution of Washington).—This account of the first study of the largest anthropoid apes by trained psychobiologists is full of interest. All lovers of nature will enjoy the illustrations of vegetation in the gorilla habitat, and the many observations of bands of these animals as they proceeded, rested, and slept in the forests of Mt. Imanyanaro and Mt. Mikeno. Several trails were followed for days at a time by Dr. and Mrs. Bingham.

Particularly important are the nesting activities, showing considerable adaptability on the part of the gorillas. Their succulent food makes them independent of drinking water. No evidence was obtained that these apes walk on their hind legs or use clubs. Even in the one instance when a large male charged a native guide, it ran swiftly on all fours, reared only while turning at the impact of a bullet, and retreated as it had come.

Most nests were found on the ground, but a few were constructed as high as sixty feet in trees, where leafy branches were folded down and trampled into a crotch so as to form a large basket-like structure. Nests are used but once; new ones are constructed, sometimes under trunks of leaning trees, wherever night overtakes the animals.

One morning the sixty gorillas of the largest band observed, before starting off to feed, held some sort of assembly, as evidenced by a trampled area of over four-hundred square feet about a huge log.

Responses of individual gorillas within the groups were by no means stereotyped. Considerable power of insight and adaptability was observed. S. C. B.

Contributions to the Genetics of the Domestic Rabbit. I. English and Dutch Spotting and the Genetics of the Hotot Rabbit, by W. E. CASTLE. II. Albino Allelomorphs of the Rabbit with special reference to Blue-eyed Chinchilla and its Variations, by PAUL B. SAWIN. Pp. 62; 12 pls., 8 tables. Washington, 1932 (Publication No. 427, Carnegie Institution of Washington).—In the first of these two splendidly illustrated papers, Dr. Castle has shown experimentally that the Hotot rabbit—an unusual French race which is all white except for a circle of colored fur about each tered and often conflicting nature of the literature of avian paleontology, have contributed to our neglect of the subject. This unfortunate situation has been remedied by the publication of the volume under review. Through this highly praiseworthy volume by Lambrecht the study of fossil birds comes into its own.

A. S. ROMER.

ZOOLOGY.

Check-List of North American Amphibians and Reptiles; by LEONARD STEJNEGER and THOMAS BARBOUR. Pp. xiv, 185. 3d edition. Cambridge, 1933 (Harvard University Press).—In preparing the new edition of this indispensable Check List, the authors have retained the general plan of preceding issues, and have included all forms described since the last unless there is serious question as to their validity. Justifiable conservatism is shown in retaining the names of the old list "except when absolutely compelled by the facts to make a change." S. C. B.

Contributions to Embryology. Publication No. 433, Carnegie Institution of Washington, 1932. Includes embryological papers as follows:

No. 134. Studies in the Reproduction of the Monkey *Macacus (Pithecus) rhesus*, with Special Reference to Menstruation and Pregnancy, by CARL G. HARTMAN. Pp. 1-161; 6 pls., 39 text-figs.

No. 135, On the Female Reproductive Tract of the Gorilla, with a Comparison of that of other Primates, by GEORGE B. WISLOCKI. Pp. 163-204; 12 pls., 4 text-figs. These two papers add greatly to the knowledge, hitherto scanty, of the reproductive anatomy and physiology of primates.

No. 136. Observations on the Bones of the Skull in White and Negro Fetuses and Infants, by MARCIANO LIMSON. Pp. 205-222; 13 figs.—Racial differences are found to exist chiefly in the formation of the maxilla and occiput. Bones of the cranial region oftener show abnormal conditions than those of the facial. Anomalies are much more common in foetal than in adult skulls.

No. 137. The Living Egg and Early Stages of its Development in the Guinea-pig, by RAYMOND R. SQUIER. Pp. 223-250; 2 pls., 2 figs.—Eggs within three or four hours after leaving the ovary proceed rapidly to about the middle third of the Fallopian tube and remain there as long as thirty hours. They progress slowly through the remainder of the tube, entering the uterus in the 8-celled stage at about the age of 80 hours. The author finds that contrary to popular opinion, this animal does not breed prolifically; the average number of ovulations per animal at one period is three. Since the period of gestation averages 62 days, only 12 to 15 young per year can be produced by one female.

p. 453). "The position of the siphuncle in the nepionic stage in ammonites was extremely variable and has no phylogenetic significance" (p. 460). Finally, "a classification based on a single character can never be either natural or even practicable" (p. 431). "All characters must be used as a basis for classification and all are variable" (p. 460). "Even if we place the suture line first, for systematic purposes, it can only be used in conjunction with the development of all other characters of the shell" (p. 440).

The phylogeny of the cephalopod, as seen by Spath, is as follows: "It is found that the earliest cephalopods are holochoanites, without endosiphuncular structures, and that they include no orthochoanites or cyrtochoanites" (p. 455). This earliest stock gave rise to the Endoceratidae and Orthoceratidae (out of which came the Belemnoidea or Dibranchiata), and other phyletic lines resulted in *Piloceras*, *Clarkoceras*, and *Tarphyceras*, which gave rise to the Nautilidae. Out of the latter family came the side line *Lobobactrites*, and the progressive stock of Ammonoidea. The octapods "may have been derived from an early decapod type (perhaps the Triassic aulacoceratids) before the three principal decapod stocks (Belemnoidea, Sepioidea, and Teuthoidea) had become distinct. . . But the view that at least some of the present-day dibranchiates represent the shell-less descendants of an ammonite stock is not so impossible as is generally believed" (p. 457). C. S.

Handbuch der Palaeornithologie; by KALMAN LAMBRECHT. Berlin, 1933. Pp. xix, 1024; 4 pls., 209 figs. (Gebrüder Borntraeger, 115 RM.).—This is a comprehensive, critical and fully documented account of fossil birds, based upon both a truly exhaustive search of the literature and a first-hand knowledge of practically all the European material. The introduction (pp. 4-57) treats of avian osteology. The major section of the work (pp. 58-649) is systematic. Full references to the literature are given for each species; also general discussions of phylogeny, relationships and adaptations are given for the more important groups. For each order references to the osteology of recent forms and a tabular presentation of fossil types are included. Pages 650-792 are occupied by a stratigraphic treatment, and a concluding "palaeobiological" section discusses such topics as fossilization processes, non-skeletal traces of fossil birds, adaptations for flight, food-gathering and combat, pathology, the origin of birds, and the "ratite" problem. The wealth of bibliographic references is notable (about 350 references on Moas, for example). Apart from Mesozoic toothed forms and a few of the more spectacular flightless types, birds are usually neglected by most writers and teachers in the field of paleontology. The specialized nature of the field of bird osteology, but more particularly the widely scatin which the siphuncle originates and lies very close to the margin, and accordingly gives rise to the siphonal lobe of the goniatids-ammonids. Many initial chambers are illustrated on the four plates with their seventy-two figures.

Schindewolf, like Lankester before him, looks for the original cephalopod in a *Patella*-like mollusc, and not among the chitons, pteropods, or tentaculites. He holds that *Volborthella* is a Lower Cambrian cephalopod and in this agrees with Grabau, Teichert, H. Schmidt, and Troedsson; he adds, however, that *Volborthella* is probably not in the direct line of evolution, but is, rather, a side branch that soon died out. He also holds that the nautilids started in the Lower Cambrian as straight shells, and that out of them arose, in Upper Cambrian time, the bent and coiled forms, and out of the latter evolved uncoiled shells. The ammonid stock also started in straight shells (bactritids), he thinks, and thence evolved into *Gyroceratites-Mimagoniatites-Agoniatites, Anarcestes,* etc. This evolution is described at length on pages 66-104. An important bibliography occupies pages 107-115.

Doctor Schindewolf has produced convincing evidence in this memoir that the ammonids arose in the straight-shelled group of Bactrites, which evolved in the Ordovician out of some *Orthoceras*-like nautilid. C. S.

The Evolution of the Cephalopoda; by L. F. SPATH. Biol. Reviews, **8**, No. 4, pp. 418-462, 13 text figs., 1933.—This clearly written, critical paper should be read in connection with that of Schindewolf, reviewed above, which meets many of Spath's objections. The latter holds that the problem of the evolution of the Cephalopoda "must be restated." He does not believe that the ammonids arose in a straight nautilid like *Bactrites,* which is "merely an *Orthoceras* with a marginal siphuncle." On the other hand, "orthocones and nautilicones (at first, ophiocones) developed independently from the primitive cyrtocone. . . Most gyrocones and cyrtocones (and some orthocones) were uncoiled nautilicones or special adaptations" (p. 459). However, Spath's statement that "no series from straight to coiled are known but only such as go in the reverse direction, in Nautiloidea as in Ammonoidea" (p. 460) does not appear to the reviewer to be borne out by the chronologic record.

Spath says that *Volborthella* and *Salterella* "are the most unconvincing 'cephalopods' that could be imagined" (p. 453). "There may have been an abortive attempt of some primitive pteropod stock at septation or tabulation, but it was almost certainly independent of the true cephalopod ancestor" (pp. 454-455). The cephalopods arose "in some chamberless and septaless form . . . shaped like an open cup, and by the differentiation of the visceral sac air chambers were formed and the siphuncle produced" volumes through the press, and four years of preliminary work. In the brief preface to the last volume the editor indulges in some retrospections. Some 50 authorities have collaborated in preparing this encyclopedic "Handbook." The difficulties of getting teamwork will be obvious to those who have tried with far less numbers.

The purpose in view in preparing the Handbook was far different from that in writing a textbook. The aim was not merely to give the existing body of assured knowledge, but to give the full historical development of the subject and to present in detail the unsolved problems. To the criticism made that the scope of the Handbook is altogether too broad, Dr. Blanck rejoins that the regolith is a thing of widest distribution over the Earth's surface and as such is therefore susceptible of the widest scientific treatment. The real purpose of the Handbook is to raise the study of the regolith to the rank of an independent scientific discipline.

At the end of Vol. X there is a general index of the subject-matter in Vols. I-X. ADOLPH KNOPF.

Vergleichende Morphologie und Phylogenie der Anfangskammern Tetrabranchiater Cephalopoden. Eine Studie über Herkunft, Stammesentwicklung und System der niederen Ammoneen; by OTTO H. SCHINDEWOLF. Abh. preuss. geol. Landesanst., N. F., Heft **148**, pp. 1-115, 4 pls., 34 text figs., 1933.—This memoir has great importance for all students of shelled cephalopods, in that the much disputed evidence for the origin of the ammonites is here reëxamined with the greatest care, and a great deal of new evidence presented which has accumulated since the work of Hyatt (1872-1900). Some of Schindewolf's fundamental conclusions are: (1) that the first chamber of nautilids is never chitinous but always of a calcareous nature; (2) that the first chamber in ammonids is the morphologic equivalent of that in nautilids; (3) that the cicatrix seen in the nautilids, and in some ammonids, is not the scar of attachment of a "protoconch" which failed of preservation, and not the secondarily closed opening through which the embryo slipped into the first chamber, but instead is a scar or deformation produced by the pull of the siphon, which was originally attached to the inside of the shell at this point; (4) that the first chamber in nautilids and in ammonids is the protoconch. This initial chamber is largest and widest in the older nautilids, where it is conical or patelloid in form; it is retained in this form by the breviconic nautilids, while in the longicones it is spherical, ovoid, or elongate, and is constricted anteriorly. The latter type of initial chamber was inherited by the bactritids, out of which the ammonids developed; in other words, there is no fundamental or ordinal difference between the first chambers of nautilids and those of ammonids. The first change of ordinal significance appears in the Ordovician bactritids,

SCIENTIFIC INTELLIGENCE.

Geology and Paleontology

Physics of the Earth—VI: Seismology. Bulletin 90 of the National Research Council, Washington, D. C., 1933. Pp. 223; 28 figs. (Paper $2.00, cloth $2.50.)—Numerous scientists who try to follow the rapid development of seismology will welcome this authoritative and up-to-date treatment of the subject. The book consists of twenty chapters, each written by a recognized authority; the authors are J. B. Macelwane, H. O. Wood, H. F. Reid, J. A. Anderson, and P. Byerly. Subjects discussed include: Causes of earthquakes, methods of field investigation, the several types of seismic waves, principle of the seismograph, analysis of earthquake records, and seismic geography. Some of these subjects require mathematical treatment, but in general the book is not highly technical; in fact, the avowed aim is "to enable scientific workers in other fields to acquaint themselves with some of the principal seismological problems, methods, and results." Each chapter has a useful list of references to other books and articles.

CHESTER R. LONGWELL.

Handbuch der Bodenlehre; edited by E. Blanck. 10 volumes. Berlin, 1929 to 1931 (Julius Springer).—This great handbook is now complete. Four of the earlier volumes have already been noticed in the Journal (in volumes 17, 18, 19, 26). The remainder are, as follows:

Vol. IV. Aklimatische Bodenbildung und fossile Verwitterungsdecken. Pp. viii, 334; 32 figs. 1930. (RM. 36.)

Vol. VI. Die physikalische Beschaffenheit des Bodens. Pp. viii, 423, 104 figs. 1930. (RM. 46.60.)

Vol. VII. Der Boden in seiner chemischen und biologischen Beschaffenheit. Pp. viii, 473, 72 figs. 1931. (RM. 52.)

Vol. VIII. Der Kulturboden und die Bestimmung seines Fruchtbarkeitszustandes. Pp. viii, 714, 21 figs. 1931. (RM. 76.)

Vol. IX. Die Massnahmen zur Kultivierung des Bodens. Pp. viii, 583, 82 figs. 1931. (RM. 66.)

Vol. X. Die technische Ausnutzung der Bodens, seine Bonitierung, und kartographische Darstellung; mit Generalregister zu Band I-X. Pp. ix, 633, 51 figs., 4 pls. 1932. (RM. 76.)

For each bound volume 3 marks are added; 10 per cent discount is allowed on Vols. IV and VII.

It is to be noted that the term "Boden" is used in an extraordinarily broad way, practically synonymous with G. P. Merrill's regolith—"the entire mantle of unconsolidated material, whatever its nature or origin." It required three and-a-half years to see the gen nucleus, for instance, the following reaction is consistent with the observations:

$$n_1^0 + N_{14}^{7+} \longrightarrow B_{11}^{5+} + He_4^{2+}$$

The neutron penetrates the nitrogen nucleus, leaving the charge of the latter unchanged but increasing its mass by unity. An α-particle is then emitted producing the copious ionization of the surrounding gas by which it is identified, which leaves a nucleus of charge +5 and mass 11, i.e., a nucleus of boron.

Work has been done to determine the ranges of these ejected neutrons in various materials and their direction of ejection. Such investigation is more difficult than usual, since the neutron leaves no visible track in a Wilson cloud chamber as do charged particles, but its existence and its behavior must be inferred from its source and from the effects it produces at impacts with other particles. Neutron speeds have been found in certain cases to be in the neighborhood of 10^8 centimeters per second and they have been known to penetrate 5 centimeters of lead without appreciable diminution in number. So far there has been difficulty in devising a theory of the constitution and the properties of this new particle. The most obvious procedure is to suppose a neutron formed by some sort of intimate union between a proton and an electron which coalesce so closely that no appreciable external electric field results. Such hypotheses cannot be said to have been successful and the possibility of course exists that the neutron is an independent variety of particle. In the meantime, knowledge of its properties is growing both in volume and in accuracy, thus providing a greater opportunity for progress along theoretical lines.

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Destouches, J. L.: Actualités Scientifiques XXXIII: Exposés de Physique Théorique III (Hermann et Cie., 1932).

electron), resulted in what seemed to be fantastically high values. The matter was soon settled by Chadwick who found that the penetrating rays produced by bombarding beryllium with α-particles could eject high speed atomic nuclei from many light elements, such as lithium, helium, carbon, nitrogen and oxygen, as well as from hydrogen. From the ranges of these particles their speed of ejection was calculable by methods known to radioactivity. Assuming an impact process throughout the phenomenon, it was then possible to compute back to the energy possessed by the penetrating ray, whether photon or material particle, and compare this with the energy in the original stream of α-particles. The calculations based on the assumption of photons as the mysterious rays resulted in values for their energies not only improbably high but values bearing no relation to the energy of the original α-particles. Whereas, assuming material particles, the energy values were directly correlated with the α-particle energies producing them. Accepting the rays therefore as material particles their mass proves by calculation to be about 1.05 times that of the hydrogen nucleus; the uncertainty in measurement is such that it is supposed that their masses are quite close to that of hydrogen atoms. Their inability to ionize gases through which they pass and their extraordinary penetrating power indicates that they lack electrical charge, hence they have been christened "neutrons." It appears from these experiments that the neutron is an additional probable constituent of atomic nuclei.

The new type of atomic reaction that appears more than probable in these experiments is extremely interesting, involving, as it does, the artificial transmutation of atoms. For example, on bombarding beryllium (Be) with α-particles (He^{++}) it is supposed that the following reaction occurs:

$$Be_9^{+4} + He_4^{+2} \longrightarrow C_{12}^{+6} + n_1^0$$

where the subscript denotes the atomic weight, the superscript the charge on the nucleus, and n denotes a neutron. In words the α-particle penetrates the beryllium nucleus and remains embedded there, thus raising its positive charge to +6 thereby forming a nucleus of carbon, and increasing its mass to 13, a rare isotope of carbon recently discovered. The next step is the emission of a neutron which leaves a normal carbon atom of mass 12. Similarly, when the neutron strikes a nitrodisturbances set up during rearrangement of the nucleus. However, since the helium atom has an atomic weight of four, and since the mass of an electron is negligible, in order to account for atomic weights other than multiples of four, a third constituent of the nucleus had to be postulated, namely the hydrogen nucleus or proton, of mass approximately one, and of unit charge. It then became possible to build the entire periodic system of atoms out of these three constituents, but not possible to do so uniquely; there remained the uncertainty as to the relative numbers of protons and α-particles, as well as the problem of the exact formation of the α-particle itself, presumably four protons and two electrons. Such a system was consistent with the known values of the atomic numbers of the elements, the physical significance of which is the net positive charge on the nucleus, in terms of the electron's charge as a unit. The discovery of isotopes, or atoms differing only in mass but not in kind, and the subsequent search for the complete list of isotopes disclosed that all known atoms possessed masses quite approximately integral multiples of a common unit close to the mass of a hydrogen atom, and this evidence was chiefly responsible for the hypothesis which has just been stated concerning the structure of nuclei.

Such was the situation until the year 1930, except for a suggestion of Sir Ernest Rutherford who postulated in 1920 a neutral particle as being the simplest way to account for the structure of the nuclei of heavy elements. No such particle had been detected, although it was of course realized that the detection of an electrically neutral particle would be extremely difficult. In 1930 Bothe and Becker found in bombarding beryllium and boron with α-particles that some extremely penetrating rays were produced, which they supposed were γ-rays. But Irène Curie and Joliot, in repeating these experiments, found the rays to be even more penetrating and in addition to have the power of causing the emission of protons from substances rich in hydrogen. The phenomenon was at first supposed to be patterned after the Compton effect, according to which a photon (X-ray or γ-ray) may strike a particle and communicate energy to it. But hitherto only electrons had been observed to experience such encounters. Furthermore, a calculation of the frequency required of photons, in order to impart the observed high velocities to particles of relatively large mass such as a proton (1800 times the mass of an

A NEW CONSTITUENT OF THE ATOM: THE NEUTRON.

A. T. WATERMAN.

From the very earliest times attention in physical science has naturally been centered upon the problem of the constitution of matter. Following the able speculative endeavors of the Greeks and the brilliant success of the atomic theory, the present century found this problem in one of its phases narrowed down to the question of the constitution of the atom. With the discovery of the atomic nucleus and with the isolation of the electron the structure of the atom began to assume a more tangible aspect, until in 1913 the atomic model of Niels Bohr seemed to offer not only a definite picture of at least the simplest atoms but also a structure which could adequately perform the function of emitting and absorbing light in accordance with the exacting requirements of spectroscopy. Although time has shown that the atom cannot be so simple and so conceivable a structure as Bohr postulated, nevertheless the constituents of the Bohr atom appeared for some time to be capable of explaining all phenomena in which atoms were involved. In further pursuit of knowledge concerning the fundamental constituents of matter the composition of the nucleus became the next question of importance. At first direct experimentation was exceedingly difficult since the most promising information came from radioactivity. That fascinating subject not only involved rare and costly materials but its study had to be confined in the main to patient and ingenious observation of such information as nature saw fit to divulge. No way was found to affect the natural progress of radioactive disintegration, and as a consequence progress in understanding the behavior and constitution of atomic nuclei was slow. At this stage it was known that the fundamental difference between different elements lay in the positive electrical charge of their nuclei. In the case of the radioactive elements the occasional spontaneous change of an atom into one of another variety was generally accompanied by emission of α-particles (doubly-charged positive ions of Helium, i.e. Helium nuclei) or β-particles (electrons) and γ-rays (penetrating electromagnetic waves or "photons"). It was naturally supposed therefore that two constituents of the nucleus were α-particles and electrons, the γ-radiation being due to

Sides broadening anteriorly, reaching the greatest width behind the compound eyes, then curving gently inward to end abruptly at the anterior margins. No ocelli or ornamentation apparent. Length of carapace: 33 mm.; width at base, 31 mm.; greatest width, 34.5 mm.

Compound eyes elongate, kidney shaped, broadest posteriorly; about one-sixth as long as carapace; situated approximately midway between the base and the anterior margin and a little less than one-fourth the width from the lateral margin. Left eye of the type distorted and pushed back. Length of compound eye, 5 mm.

Of the five preabdominal tergites, only the first is complete. This is a narrow band, breadth about seven times the length. Each succeeding tergite decreases in width, giving the specimen a tapering appearance. Lateral margins of the tergites straight, forming an angle with the anterior and posterior margins; no ornamentation apparent. Measurements of first tergite: length at anterior margin, 31 mm.; length at posterior margin, 29.5 mm.; width, 4.5 mm.

Horizon and Locality:

Upper Moscow Shales. The specimen was found in a quarry of the Portland Cement Company near Ludlowville, N. Y.

Remarks:

It is of interest to note that this species was found associated with a typical marine fauna. Several Spirifers and fragments of Trilobites are scattered throughout the matrix.

As compared to the two common Silurian forms, *Eurypterus remipes* DeKay and *Eurypterus lacustris* Harlan, the relative lengths of the carapaces are sufficient to distinguish the species.

The writer wishes to express his gratitude to Dr. Rudolf Ruedemann who very kindly contributed many helpful suggestions.

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NOTE ON A NEW EURYPTERID FROM THE MOSCOW SHALES OF NEW YORK.

ERIK N. KJELLESVIG.

Unlike the Silurian which exhibits a rich eurypterid fauna, the New York Devonian has yielded only three species of eurypterids. These are *Stylonurus wrightianus* (Dawson), from the Portage, *Stylonurus excelsior* Hall, from the Catskill, and *Pterygotus inexpectans* Ruedemann, from the Hamilton.

In 1919, Ruedemann described *Pterygotus inexpectans* from the "Oneonta sandstone" at the top of the lower falls of the Manor Kill, Gilboa, N. Y.[1]

This is the only eurypterid of that genus ever found in the Devonian of New York. At a later period, these beds at Gilboa were found to be Upper Moscow in age.[2]

Pterygotus inexpectans is the only Hamilton eurypterid of which the writer has any record. To this we can now add another species, and it is on this new form that the following paper is based.

The new species is represented by a single individual exhibiting a carapace and fragments of the first five tergites. A description of the specimen is difficult because of the poor state of preservation and the very unfortunate absence of the appendages. The total lack of appendages has made it impossible to determine the exact generic position. From the rather scanty evidence furnished by the specimen, it would seem most probably to be referable to the genus Eurypterus, although the possibility of its being a Stylonurus must be admitted. It is hoped that a future discovery of more complete material will determine the correct generic position. The species has been named after Dr. Gerald R. MacCarthy who collected the specimen near Ludlowville, N. Y.

EURYPTERUS (*Stylonurus*?) MACCARTHYI, n. sp.

(Figure 9.)

Carapace subquadrate in general outline; length almost equalling greatest width; base nearly straight, forming an approximate right angle with the posterior lateral margins.

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[1] Ruedemann, R., N. Y. State Mus. Bul. 227-228, p. 88, 1919.

[2] Cooper, G. Arthur, Stratigraphy of the Hamilton Group of Eastern New York (abstract), Bull. Geol. Soc. America, vol. 44, pl. 1, pp. 200-201, 1933.

of the Normanskill shale and, especially, the Schenectady shale, hence their much less common occurrence.

To summarize our observations on the eurypterids in the graptolite-shales of New York, they clearly indicate that the eurypterids and graptolites did not have a common habitat and became associated only post mortem, in a common burying ground. The graptolites were denizens of the open oceans, partly as free plankton and partly as epiplankton (pseudoplankton of authors). Whether the eurypterids already in Ordovician and Silurian time lived in fresh water, as many believe and as they did in Carboniferous time—or inhabited the lagoons and embayments and other protected parts of the littoral region, perhaps also its deeper reaches, is not readily determined by their occurrences in the graptolite shales; but other evidence constrains the writer to believe in their marine habitat and origin notwithstanding the claims of some students of the group.

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MENISCOTHERIUM ROBUSTUM SP. NOV., AND A DISCUSSION OF *HYRACOPS SOCIALIS* MARSH.

MALCOLM RUTHERFORD THORPE.

(Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn., U. S. A.)

The new species herein established differs from the four previously described in size, skull configuration, geologic horizon, and geographic locality. My thanks are due to Professor Lull for his constructive criticism of this paper. All figures were drawn by Miss Joy Stilson.

Meniscotherium robustum sp. nov.

(Figs. 1-4.)

Holotype: Cat. No. 10101 Y. P. M. Skull and jaws. *Horizon*: Lower Eocene (Knight). *Locality*: 2 miles west of Aspen, in cut on the Union Pacific Railroad, in Uinta County, southwest Wyoming. Collected by William Cleburne in 1875 for Professor Marsh.

The type skull and jaws are more complete than any so far described in this genus, lacking mainly the right zygomatic arch, the occipital condyles, and the crowns of the incisors and canines in the skull and the condyles and crowns of C, P_1, and P_2 in the mandibles.

Since this new species is nearest to *M. terraerubrae* Cope, comparison will be made with that form, and the differences between them will be emphasized.

Distinctive characters: Skull: a little more than 30% longer than that of *M. terraerubrae*; upper contour much more nearly straight without the fulness of the frontal region or the

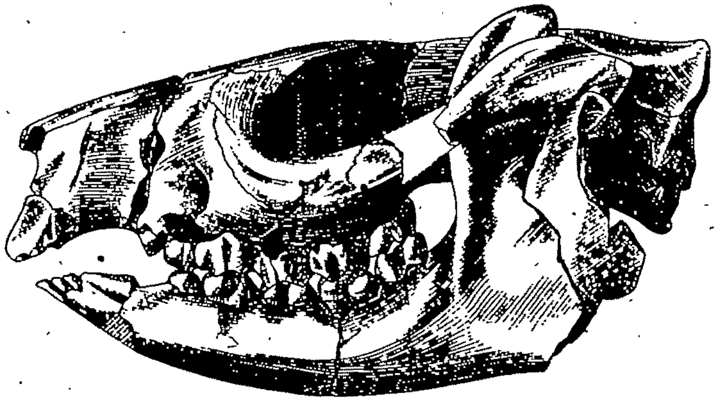

Fig. 1. *Meniscotherium robustum* sp. nov. Holotype Cat. No. 10101. Lateral view of skull and jaws. ¾ nat. size.

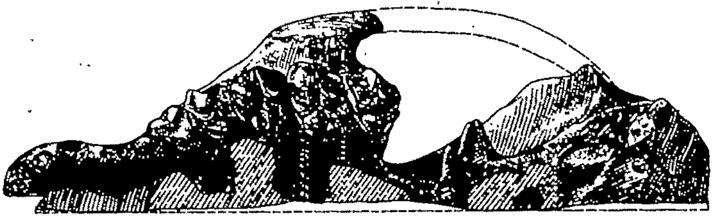

Fig. 2. *Meniscotherium robustum* sp. nov. Holotype Cat. No. 10101. Inferior view of left half of skull. ¾ nat. size. Teeth partly restored from opposite side.

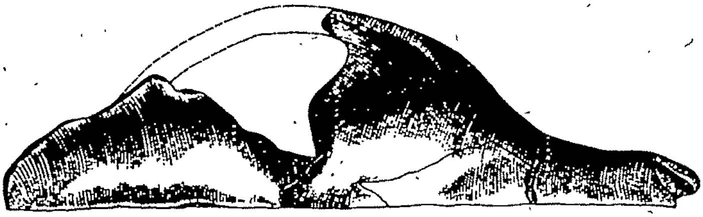

Fig. 3. *Meniscotherium robustum* sp. nov. Holotype Cat. No. 10101. Superior view of left half of skull. ¾ nat. size.

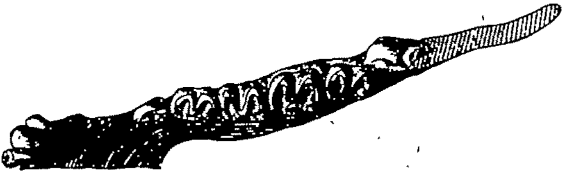

Fig. 4. *Meniscotherium robustum* sp. nov. Holotype Cat. No. 10101. Superior view of right ramus. ¾ nat. size. Teeth partly restored from left side.

marked slope of the contour from it both anteriorly and posteriorly; muzzle more sharply contracted at a point just in advance of the infraorbital foramen from whence anteriorly it maintains a uniform width; postorbital constriction quite pronounced; orbits unusually large, open posteriorly, and with a small post-orbital process from the frontal but none from the malar; temporal ridges low, thick, and heavy, rapidly converging to form a moderately low and narrow sagittal crest; nuchal crest strong and moderately prominent, extending upward and backward; infraorbital foramen 5 mm. in maximum diameter situated above the anterior part of P^4; lateral expansion of nasal bones considerably greater (maximum width 20 mm.) but acuminate posteriorly; malar large, reaching small lacrimal, and lacrimal foramen just inside orbital margin; premaxillaries small and maxillaries large; frontals depressed between orbits; anterior narial opening relatively large, partly overhung by the downwardly projecting anterior termination of the nasals; incisive foramina small and within curve of the incisors; palate but slightly concave, and doubly excavated posteriorly to a line opposite the hypocone of M^2.

Mandible constricted on a line just posterior to P_2; symphysis 27 mm. long, firmly fused, with a slope of about 30° from the horizontal; rami robust, compressed only below the coronoid process, the latter being quite high with almost vertical anterior edges; the low anterior ridge defining the shallow masseteric fossa dies out rather abruptly immediately posterior to M_3 and about the middle of the depth of the ramus.

Superior teeth: *Meniscotherium* has the complete dentition of 44 teeth. *Incisors*: crowns missing but alveoli indicate teeth of nearly uniform size, about 3 mm. in diameter, arranged in a half circle, and with roots nearly circular in cross-section. *Canines* apparently rather small, weak teeth but larger than incisors. *Premolars*: P^1, double-rooted and separated from canine by a diastema of 1.5 mm.; P^2, double-rooted, triangular in outline without heel or cingulum and apparently separated from P^1 by a diastema of 2 mm.; P^3, outer face nearly flat but divided medially by a slight depression, cingulum on posterior side only, inner tubercle moderately prominent, much larger than P^2; P^4, considerably larger than P^3 and quite similar to M^3, external face divided into 2 apices separated by a well-marked ridge, anterior part divided medially by a faint ridge but not so with posterior moiety, antero-external angle moderately prominent, cingulum around anterior, inner, and posterior sides of lingual tubercle, well-developed intermediate crest parallel to antero-external apex and a corresponding one parallel to postero-external apex, the former crescentic and the latter straight, except for turning inwards at its posterior extremity where it joins the posterior cingulum. *Molars:* parastyles and mesostyles unusually prominent on all molars. Anterior cingulum present, but M^1 and M^2 have no posterior one and only a trace of an internal cingulum between protocone and hypocone, protoconule parallel to paracone, protocone a little more conical and prominent than hypocone, the latter being confluent with metaconule; M^3 has but the protocone internally, surrounded by a basal cingulum, especially heavy anteriorly and posteriorly, protocone nearly as conical as the internal cusp of P^4, protoconule more prominent than metaconule, latter lying on posterior cingulum. There is a thickening of, and a small prominence on, the middle of the anterior cingulum.

Inferior teeth: *Incisors*: crowns apparently more procumbent than the upper, extending forward at an angle of 30° from the horizontal, but, as the crowns of the superior incisors are missing, this cannot be determined at present. Median incisors smaller than second pair, outer pair probably size of first pair; crowns smooth. *Canines*: crowns missing, but alveoli indicate teeth at least twice the size of the incisors; incline forward. *Premolars*: P_1, small, compressed, single-rooted; P_2, small and apparently single-rooted; P_3, unlike molars, much larger than P_2, with median cutting edge and set obliquely in jaw, directly behind where the rami are constricted. P_4, about ⅓ larger than P_3 and superfically resembling molar pattern. The anterior half is approximately the same size as posterior, whereas in the molars the anterior part is smaller than the posterior. It is same length as M_1 but somewhat narrower. *Molars*: present a closed tooth-row with small metastylid close to metaconid, the former being smaller than usual in the typical members of this genus. The anterior portion formed by the paraconid, protoconid, and metaconid is considerably narrower (at least ⅓) than that formed by the metaconid, hypoconid, and entoconid. The paraconid tends to curve posteriorly toward the valley, while the entoconid is conical and more pronounced in M_2 and M_3 than in M_1. All the molars are of similar pattern, and none has a basal cingulum.

Measurements of Holotype.	mm.
Length of skull, total	127.5
Width of skull at base of zygoma	66.
Width of palate between fourth premolars	16.
Width of muzzle at canines	23.
Depth of skull at front of orbits, exclusive of molars	32.
Length from canine to foramen magnum, incl.	117.
Length from occipital crest to origin of sagittal crest	53.5
Length from occipital crest to anterior border of orbits, medial	82.
Length of nasal bones, maximum	54.
Width at postorbital processes	29.
Width of brain case, maximum	35.
Width of foramen magnum	14.
Length of mandibular ramus, without incisors, partly estimated	118.
Length of mandibular ramus to base of coronoid	73.
Depth of mandible at condyle, partly estimated	43.
Depth of mandible at coronoid process	63.
Depth of mandible at M_2	21.5
Depth of mandible at P_4	14.
Depth of mandible at C	8.

Measurements of Teeth of Holotype.			mm.
Length of superior dental series, $I^{1 (\text{alveolus})}$-M^3 inclusive			71.
Length of superior premolar series			27.
Length of superior molar series			30.
Length of P^2	4.7;	transverse diameter	5.
Length of P^3	7. ;	transverse diameter	8.3
Length of P^4	9.4;	transverse diameter	11.
Length of M^1	9.5;	transverse diameter	12.3
Length of M^2	11. ;	transverse diameter	13.2
Length of M^3	10. ;	transverse diameter	12.1
Length of inferior dental series, $I_{1 (\text{alveolus})}$-M_3 inclusive			68.
Length of inferior premolar series			22.
Length of inferior molar series			30.
Height of crown of I_1			5.5
Length of alveolus of C			4.
Length of P_3	7. ;	transverse diameter	5.
Length of P_4	9. ;	transverse diameter	7.
Length of M_1	8.5;	transverse diameter	8.
Length of M_2	10. ;	transverse diameter	8.
Length of M_3	10. ;	transverse diameter	7.

Key to Species of *Meniscotherium* (measurements from types; in part from Granger, 1915.)

A. Strong metastylid on all three lower molars
  M. chamense .... $M^{1-3} = 21$ mm.
  M. terraerubrae .... $M^{1-3} = 26$ mm.
  M. priscum (skull not known)
B. Moderate metastylid on lower molars
  M. robustum .... $M^{1-3} = 30$ mm.
C. Weak metastylid on M_3, absent on M_2 and M_1
  M. tapiacitis .... $M^{1-3} = 17$ mm. est.

Geological horizon: *M. priscum*, the only previously described type from Wyoming, was collected in the Clark Fork beds (uppermost Paleocene) and is the earliest form known. *M. robustum* sp. nov. came from the Knight beds (middle Lower Eocene) of the uppermost division of the true Wasatch. The Knight beds Granger (1914) correlates with the Lower Wind River or Lysite, and this is the first recorded appearance of *Meniscotherium* in this horizon. The type specimens of the other three species are from the New Mexico Largo beds, upper division of the Lower Eocene and correlated mainly with the Wyoming Lost Cabin beds (Upper Wind River, i.e., Late Lower Eocene). Fragmentary specimens of *M. chamense* were found in 1909 by an American Museum party, on Muddy Creek, Wind River Basin, and on Alkali Creek, both in Fremont County, Wyoming, in typical Lost Cabin beds.

Therefore this new species is older than the typical forms of *Meniscotherium* but younger than the Clark Fork, and it helps in some measure to bridge the gap of several hundreds of feet of strata in which this genus has not been found previously. It is quite possible, if more material were found referable to *M. priscum*, that this form would be placed in a new genus. If so, *M. robustum* would then be the oldest form, so far as we know now.

Geographic locality: Three of the four previously described species were collected in northwestern New Mexico and the fourth from the Clark Fork Basin, Park County, northwestern Wyoming.

The locality of this new species lies about midway between these two areas, but a little nearer the Clark Fork Basin, that is, in the Wasatch Basin, west of Aspen, southwestern Wyoming.

Discussion of *Hyracops socialis* Marsh, 1892.

In 1878 at the head of Gabilan Canyon, a branch of Canyon Largo on the east side, near the boundary between Rio Arriba and Sandoval Counties, New Mexico, David Baldwin collected for Professor Marsh parts of skulls and skeletons of at least 35 individuals, which are referable to *Meniscotherium*, and specifically to *M. terraerubrae* Cope 1881. All this material was in a hard brick-red matrix. There are several trays of these fossils, among which were the specimens of *Hyracops socialis*, but Professor Marsh failed to indicate the types, with possibly one exception. From this material new information is herewith recorded.

Professor Marsh recognized the fact that many of these fossils agreed closely with Cope's *Meniscotherium* (1874-1882). In addition there were other specimens which were not typical in that "the last premolar is nearly or quite like the molars." There are maxillae with teeth which fit this description, and, after careful comparison, I am convinced that these are of the milk dentition of *Meniscotherium*. In fact, I believe that Professor Marsh recognized this subsequent to his 1892 paper, because on the box containing Cat. No. 10562 he had written, "Skull with *milk teeth.*"

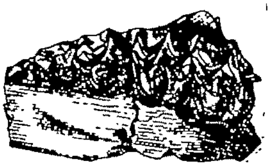

Fig. 5. *Meniscotherium terraerubrae* Cope. Cat. No. 10561. Inferior view of left maxilla with deciduous P^2, P^3, and P^4 and first two true molars. Nat. size.

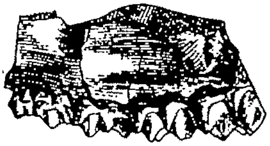

Fig. 6. *Meniscotherium terraerubrae* Cope. Cat. No. 10561. Left lateral view of Fig. 5. Nat. size.

Cat. No. 10561 Y. P. M. is a left maxilla with dp^{2-4} and M^{1-2} wherein dp^4 (Figs. 5-6) is molariform but somewhat more quadrilateral than the molars. Dp^3 is nearly right triangular with the outer and posterior sides nearly equal, while dp^2 has the postero-internal cusp much developed.

Measurements of Cat. No. 10561 Y. P. M.

dp^2 antero-posterior	4.8 mm.	transverse	3.3 mm.
dp^3 antero-posterior	6. mm.	transverse	5.4 mm.
dp^4 antero-posterior	7.5 mm.	transverse	8. mm.
M^1 antero-posterior	9. mm.	transverse	10. mm.
M^2 antero-posterior	10.2 mm.	transverse	10.6 mm.
Total length, dp^{2-4}	17.5 mm.		

There is no diastema between dp^3 and dp^4, as sometimes occurs here in the permanent dentition.

Cat. No. 10562 Y. P. M. is a right maxilla with much of the palate present and with right dp^{3-4} and M^{1-3}. The molars are fully erupted, and the deciduous premolars are quite worn but show the same characteristics as in the specimen just described above.

M^3 antero-posterior	10. mm.	transverse	12. mm.
Length of M^{1-3}	26. mm.		

Cat. No. 10551 Y. P. M. is another maxilla with dp^4 having a prominent middle style. In this case there is a slight variation in size from No. 10561, as follows:

dp^3 antero-posterior	5.5 mm.	transverse	6. mm.
dp^4 antero-posterior	7.3 mm.	transverse	8.5 mm.
M^1 antero-posterior	8.2 mm.	transverse	9.7 mm.
M^3 antero-posterior	9.5 mm.	transverse	11. mm.

With this specimen is a femur without epiphyses, the maximum length of which is 85 mm. There are shown nearly all stages in the development of the dentition in addition to those with milk premolars. Cat. No. 10558 Y. P. M. shows the molars completely erupted, while the tips of the permanent premolars are just on a level with the alveolar parapet. Another specimen shows M^3 just beginning to erupt. The type measurement of 26 mm. for the length of M^{1-3} inclusive holds true for most of these specimens, but some measure 27 mm. and one (Cat. No. 10276 Y. P. M.) even 27.5 mm., while the lower molars measure 29 mm. This latter specimen is a laterally crushed skull and jaws, so that transverse measurements are not reliable. It probably was a male.

A second generic distinction was the presence of four fused vertebrae in the sacrum of Marsh's specimens, while Cope mentioned but three in *Meniscotherium*. Cat. No. 10557 has a complete sacrum (four ankylosed vertebrae) 56 mm. long with a maximum width across the transverse processes of the sacral (anterior) vertebra of 35 mm. Subsequent to Marsh's description two sacra were found in Cope's collection with four coössified vertebrae, one being used in the mount of *Meniscotherium* in the American Museum of Natural History. Consequently this distinction no longer seems valid.

With Cat. No. 10552 is a complete mesosternal segment, 12 mm. in antero-posterior length, 11 mm. in transverse, and 3 mm. in thickness, all maximum measurements.

Previous to Marsh's description of *Hyracops*, Cope had figured most of the skeletal parts of *Meniscotherium* except the feet. Marsh's figure of the manus (1892) was based on a nearly complete forefoot with the carpal elements somewhat disarranged and still partially in the matrix. This is Cat. No. 10553, marked "D," and is larger than the forefoot figured by Granger (1915). The magnum is 6.5 mm. in height, while the lunar is 4 mm. It seems very doubtful that the magnum articulated with the cuneiform, as Marsh thought. The fact remains that the magnum is a relatively larger bone than that in the American Museum specimen. There is, however, a foreleg with humerus, radius, ulna, carpals, and metacarpals (Cat. No. 10276), partly in the matrix, the bones displaced slightly, which, although somewhat smaller, shows the magnum and lunar more nearly equal in size in the anterior aspect, that is approximately 3.5-4 mm. in diameter, and the carpals with approximately the same relations as in the American Museum mounted specimen. Of course it should be borne in mind that the latter is a composite mount, and the two Marsh specimens are still held in matrix sufficiently to show the post mortem relationships. I am of the opinion that Cat. No. 10553 represents a male and Cat. No. 10276 a female but that there is not sufficient difference in construction to warrant identifying them as other than *M. terraerubrae.* The centrale is certainly present.

Professor Marsh reconstructed the pes apparently from isolated but well-preserved bones, although in 1892 these may have been partially in the matrix, as the forefeet still are. Evidently Marsh's epicuneiform is a sesamoid, as he suggests, rather than a distinct tarsal bone in addition to the normal series.

There are several complete leg bones which give us the dimensions of *M. terraerubrae*, not previously recorded, as follows:

Cat. No. 10276	Radius	63.	mm., maximum length
Cat. No. 10276	Ulna	84.	mm., maximum length
Cat. No. 10555	Tibia	91.	mm., maximum length
Cat. No. 10556	Humerus	87.5	mm., maximum length
Cat. No. 10556	Femur	89.5	mm., maximum length
Cat. No. 10556	Calcaneum	33.	mm., maximum length*
Cat. No. 10557	Distal end of scapula	14	mm., maximum ant.-post. length
Cat. No. 10559	Middle metatarsals	29, 31, 30	mm., maximum length

Cat. No. 10557 has a complete left femur 73.5 mm. in length. It is thoroughly typical of *Meniscotherium* and may be referable to *M. chamense* Cope.

* Larger than Cope's specimen.

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WINDGAPS AND WATERGAPS IN PENNSYLVANIA.

HOWARD A. MEYERHOFF AND ELIZABETH W. OLMSTED.

In the November, 1933, number of this Journal, Ver Steeg takes issue with Hickok on the significance of windgaps as indicators of erosional levels,[1] and the conclusion reached in his exhaustive study of the subject[2] is reaffirmed; namely, that "throughout the northern Appalachian region . . . . . there is no accordance in windgap elevations and they do not mark fluvial base levels." Ver Steeg also claims in both articles that "the watergaps of to-day have varying elevations and are known not to represent a peneplane level, and the still more irregular windgaps cannot be regarded as reliable evidence that they are indicators of former peneplane levels."[3]

These conclusions seem to be based on debatable assumptions and questionable interpretations of the facts, and Ver Steeg's data invite re-examination and critical analysis.

In his initial study of the subject, Ver Steeg disagrees with Barrell, who postulated several erosional surfaces in the Appalachian region, and who used windgaps as contributive, but not critical, evidence of their existence.[4] Ver Steeg discards the Barrell hypothesis of several cyclical levels and then proceeds to demonstrate that the windgaps of Pennsylvania, ranging in elevation from 720 to 1640 feet, are not related to the Schooley and Harrisburg peneplanes, the only levels not discarded. The conclusion is drawn that they are therefore genetically unrelated to any erosional surfaces. Granted the premise, the conclusion follows; but the premise is one of the principal points at issue in Appalachian physiographic history.

In his latest paper on the subject, Ver Steeg assigns no value whatever to the variety of evidence which Hickok advances to prove the existence of several erosional surfaces in south-central Pennsylvania, but he concentrates his attack upon the limited use made of the windgaps. He objects to Hickok's method of grouping the gaps and of utilizing variable vertical intervals between the groups, on the grounds that "by using the proper interval, erosion surfaces can be made to appear at the desired elevations necessary to coincide approximately with erosion surfaces otherwise determined." He dismisses the contribution *in toto* with the statement that "the large number of erosion surfaces postulated and the few windgaps at those horizons make one question the validity of Hickok's conclusions."

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[1] Ver Steeg, Karl, Windgaps and erosion surfaces. This Journal, Fifth Ser., XXVI, pp. 507-511, 1933.

[2] Ver Steeg, Karl, Windgaps and watergaps of the Northern Appalachians. Ann. N. Y. Acad. Sci., XXXII, pp. 87-220, 1930.

[3] Windgaps and erosion surfaces, p. 507.

[4] Barrell, Joseph, The Piedmont terraces of the Northern Appalachians. This Journal, Fourth Series, XLIX, pp. 227-258; 327-362; 407-428, 1920.

It is true that the method employed by Hickok has the appearance of subjective selection, but the fact remains that, accepting Ver Steeg's correction, which involves a single error of five feet, Hickok has used no magic but merely the actual intervals and groupings in the vertical positions of the gaps. If it be granted that Hickok has erred in not avoiding the appearance of subjectively choosing his data, the need for an objective analysis is obvious. For this purpose the tables of windgap and watergap elevations prepared by Ver Steeg and reproduced here in condensed form will be utilized (Table I).

Column I contains 31 windgaps, distributed vertically from heights of 720-740 feet to 1620-1640 feet. Bench mark elevations are available for eight of the gaps, but the 20-foot contour range has necessarily been used to designate the vertical positions of the others. The 20-foot contour range must, therefore, be used in an objective analysis of their vertical distribution.

If their formation be not related to old erosional levels of cyclical origin, ideally the 31 gaps should be subequally spaced throughout the 920 feet over which they occur, and there should be approximately one gap every 30 feet, or two gaps for every three 20-foot intervals. It is interesting, therefore, to find that all the gaps in this table fall within 52%, rather than the ideal 66⅔%, of the intervals available.

If it be assumed that several levels are present in the Pennsylvania region and that the windgaps may indicate their position, a wholly objective, though somewhat arbitrary, method of grouping the gaps may be employed. Single gaps spaced at wide intervals plainly cannot be included in any group, whereas it may justly be contended that the elimination of any in a closely spaced series would be arbitrary and unwarranted. The three gaps above 1520 feet are widely spaced, as are the gaps at the 1018- and 800-820-foot levels. If these five be eliminated, the remaining 84% of the gaps fall within space limits that constitute but 40% of the total vertical range.

Table I

Elevations of Windgaps and Watergaps in eastern Pennsylvania

Elevation	I	II	III	IV
1620 — 1640	1			
1560 — 1580	1	1		
1540 — 1560		2		
1520 — 1540				
1460 — 1480		1		
1440 — 1460		1		
1420 — 1440	1	1		
1400 — 1420	1	2		
1380 — 1400	1	4		
1320 — 1340	1	3		
1300 — 1320	2	1		
1280 — 1300	3	2		
1260 — 1280		1		
1220 — 1240		1		
1180 — 1200	1	1		
1160 — 1180	2	2		1
1140 — 1160				1
1100 — 1120	2	2		
1080 — 1100	1			
1040 — 1060	1			2
1000 — 1020	1	1		1
980 — 1000	1	1		
940 — 960	2		2	1
920 — 940	1	1		
900 — 920	2	1		
880 — 900	1	1	1	
860 — 880	1		2	1
840 — 860			1	5
820 — 840			2	
800 — 820	1		1	
760 — 780			(?)2	1
740 — 760	1		1	2
720 — 740	1		1	2
700 — 720			2	2
680 — 700			2	1
660 — 680				1
640 — 660			1	3
620 — 640			2	1
600 — 620			3	3
580 — 600			1	2
560 — 580				2
540 — 560				4
520 — 540				1
500 — 520				1
480 — 500				3
440 — 460			1	1
400 — 420				1
380 — 400				2
360 — 380				7
340 — 360			2	
320 — 340				1
300 — 320				2
280 — 300				1
	31	30	27	56

I "Undoubted windgaps" in eastern Pennsylvania, east and south of Susquehanna River. From Ver Steeg. Windgaps and watergaps of the northern Appalachians. Ann., N.Y.A.S., 32, 1930, Table II, p.96.

II "Undoubted windgaps" in Blue Mountain. From Ver Steeg, idem, Table V, p.99.

III Windgaps south of Lebanon Valley. From Ver Steeg, Windgaps and erosion surfaces. A.J.S., 26, 1933, p.511.

IV Watergaps in eastern Pennsylvania, east and south of Susquehanna River. From Ver Steeg, idem, Table III, pp.96-97.

Accident may, of course, account for the results obtained in the analysis of a single set of figures, but the application of these two methods yields results of the same order in the case of the 30 windgaps included in Column II. Here the total range in elevation is 700 feet, and ideally there should be approximately one gap every 23⅓ feet; or, for the practical purposes of objective analysis, the 30 gaps should be spread over 86% of the 20-foot intervals in the vertical range available. The fact is that the gaps are all included within 57% of the space range, rather than 86%. Grouping them in the same manner employed for those in Column I requires the elimination of the gaps at 981 feet, 1018 feet, and 1220-1240 feet; the retention of the 27 others. The latter 90% fall with space limits comprising but 46.4% of the whole.

The table of windgaps south of Lebanon Valley (Column III) contains 27 gaps distributed over a 660-foot vertical range. Unfortunately, four of the gaps are included in space intervals of 40 feet (660-700 and 760-800); hence, neither the gaps nor the space can be utilized in the computation; and the highest 40 feet are gapless. The computation will therefore be based on a total range of 540 feet and 23 gaps, which ideally should be spaced approximately 25 feet apart or in 80% of the 20-foot intervals present, but which fit within 55.6% of the total range. Elimination of the isolated gaps at 440-460 feet and 520-600 feet throws 91% of the gaps into 48% of the space.

The failure of the windgap spacing to approach the ideal even remotely demands some explanation other than sheer accident. The mathematical probabilities are against fortuitous development, unless one takes seriously the claim quoted above: that "the watergaps of to-day have varying elevations and *are known* not to represent a peneplane level" or fluvial surface of cyclical origin.[5]

It is not the purpose of this article to enter into an exposition of compound gradients, knick-points, erosional terraces, and compound valleys, and their meaning in fluvial cycles of erosion. The fact that several partial cycles of development may be represented in a single stream system or in neighboring systems seems too well established to require demonstration.

An analysis of the watergaps in Pennsylvania reveals the fact that they, too, fall into groups which are separated by relatively large vertical intervals. Ver Steeg states that in this case apparent groups have no significance because the same stream, crossing several ridges, will make as many gaps at approximately the same elevation. The Susquehanna is used as an example, but a study of the elevations in the gaps of Susquehanna River shows that they have a greater vertical range than some of the higher watergaps occurring in the courses of different streams. The higher gap systems appear to be graded maturely with respect to older planes of erosion which are as yet unaffected by headward entrenchment,

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[5] No distinction seems to be made between peneplanation and fluvial gradation toward a relatively transient baselevel in either of Ver Steeg's articles, but his arguments are directed wholly against the latter idea. It must be assumed that he has the partial cycles in mind in attempting to refute Barrell and Hickok.

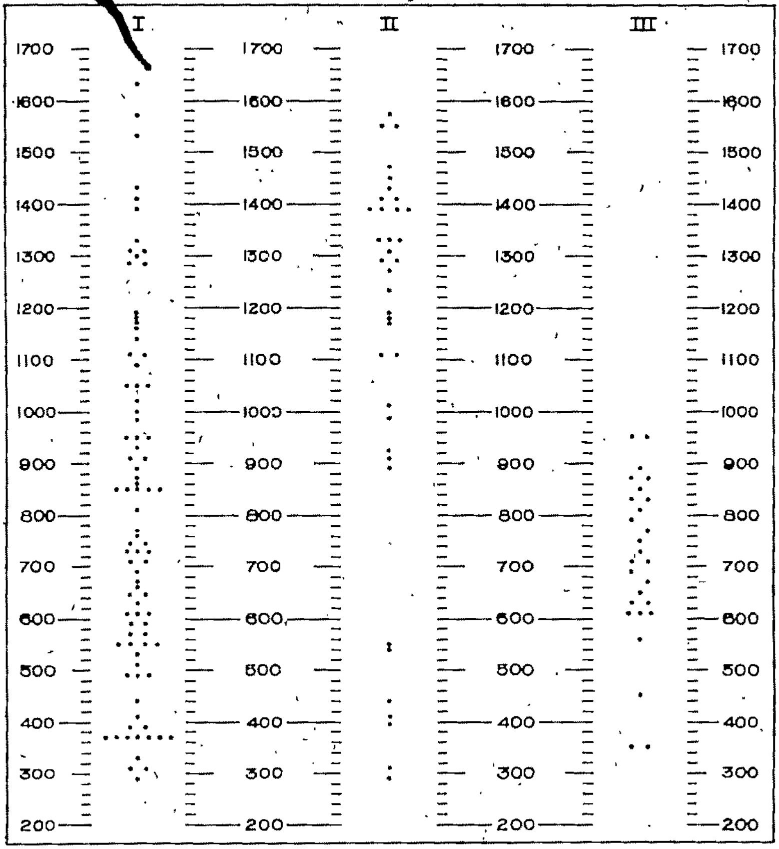

Figure 1. Vertical Distribution of Windgaps and Watergaps in Eastern Pennsylvania

I Windgaps and watergaps east and south of Susquehanna river.
II Windgaps and watergaps in Blue Mountain.
III Windgaps south of Lebanon Valley.

whereas the larger masterstream, the Susquehanna, is in a younger stage of fluvial development in a later cycle of erosion. Its gradient is for this reason steeper than the gradients of many smaller streams at higher elevations.

Table II
Elevations of Erosional Surfaces

Barrell (1920) Maryland	Bascom (1921) Pennsylvania	Knopf (1924) Pennsylvania	Stose (1928) Pennsylvania	Knopf (1929) Maryland	Hickok (1933) Pennsylvania	Levels indicated by gaps
		1660			1660	
					1520 ?	1520—1540
					1450	
					1300—1360	1360—1380
						1260—1280
					1180—1220	
1100—1150					1040—1100	1080—1100
	1000	1020	1040	1020	1000	1020—1040
					950	
920—940		900	940	900	800	920—940
				820	800	820—840
730—745	700	720	740	720	700	680—700
			640		660	
610—630	600	620	600	600—640	600+	580—600
					550	
520—540		500—580	520	500—520	500+	520—540
	400—450	320—420	440	400	450	460—480
					400+	
			380		360+	340—360

The watergaps listed in Column IV (Table I) may be analyzed as follows: There are 56 of them lying between 280 feet and 1160 feet. Here, surely, with so many units, one might expect a reasonable approximation of the ideal spacing—one gap every 15.7 feet; yet nearly 40% of the 20-foot intervals are unoccupied by gaps. Obviously, single gaps within a 20-foot interval constitute no evidence of grouping, and if these are eliminated, it is found that 78% of the 56 gaps fall within 34% of the vertical range available to them. The impossibility of ascribing such a restricted distribution to accidental causes becomes more apparent when it is found that the higher groups of watergaps coincide with the lower groups of windgaps. If all the gaps are plotted (figure 1), the bunching is even more apparent and the conclusion that they are indicators of erosional levels is all but inescapable.

A study of the accompanying chart (figure 1) makes it possible to suggest the positions of several levels without reference to other types of evidence. A single assumption is necessary: namely, that the lowest elevation in a group of gaps most nearly approximates the local base of erosion. Again to make the utilization of the data as objective as possible, the 20-foot contour range immediately beneath the lowest gaps in a series will arbitrarily be designated as the position of an erosional level. The result is tabulated in Table II, which, for purposes of comparison, includes the levels in the same general section of the Appalachian region, as determined by Barrell, Bascom, Knopf, Stose, and Hickok, chiefly from evidence in which gaps played little or no part. The parallelism is striking, and the rough accordance in elevations is noteworthy, in view of the fact that vertical variations are inevitable in different river systems draining a belt of country 150 miles long.

Three conclusions are suggested by the analysis:

(1) The Appalachian region of Pennsylvania contains the record of several erosional levels of fluvial origin.

(2) The positions of these levels are indicated with moderate accuracy by groups of watergaps and windgaps.

(3) Although isolated windgaps may have no cyclical significance, groups of windgaps are reasonably reliable indicators of fluvial baselevels.

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THE CONTRASTING PLUTONIC MASSIFS OF RIVIÈRE À PIERRE, QUEBEC.[1]

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Rivière à Pierre, a village on the river of the same name, in Portneuf County of the Province of Quebec, is 50 miles north of Quebec City and about 140 miles from Montreal. It has been the site of a granite-quarrying industry since 1894, and is the center of one of the principal areas on the north side of the St. Lawrence for supplying construction stone and curbstone. Small amounts of stone have been removed in about thirty places, and twelve large quarries have been opened. The stone exploited has come from two pre-Cambrian massifs, which show dissimilar characteristics. It is the purpose of the present paper to point out the contrasts in the two intrusive bodies: one, of granite, is the transgressive type; the other, of quartz diorite, is predominantly of the concordant type.

The observations in all the openings from which stone has been taken have given some data on the tectonics of the intrusions, although time was lacking to make an exhaustive study on account of the large size of the massifs. In all, six weeks were spent in the field.

The Grenville Series. Three series may be distinguished in mapping the bedrock geology of the vicinity. The oldest rocks belong to the Grenville series, which consists of grey paragneisses, amphibolites, quartzites, and limestones. In the immediate vicinity of Rivière à Pierre, most outcrops are of the grey paragneisses, which represent the more strongly granitized parts of the amphibolites and retain the banding found in them. The more characteristic and basic amphibolites, as well as the garnetiferous varieties, are found about two miles west of the village of Rivière à Pierre. Many of the basic members are thin-bedded and probably are derived from basic tuffs; the more massive bands were flows or sills of similar composition to the tuffs. In some places narrow bodies of amphibolite that cut across the bedding are probably the metamorphosed equivalents of basic dykes.

The thick bodies of limestone and quartzite, which are so commonly considered characteristic of the Grenville series, are lacking in the vicinity of Rivière à Pierre, but occur 10 miles west of it along the Batiscan River. Some evidence indicates

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[1] Published with the permission of the Quebec Bureau of Mines. A report on the commercial granites of this and other districts on the north side of the St. Lawrence River is in press.

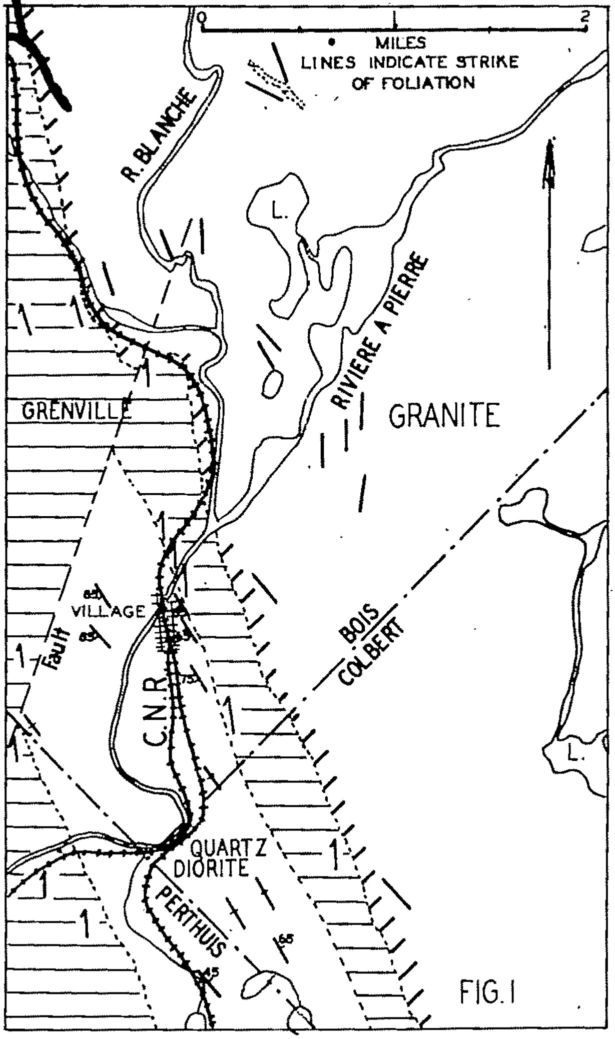

FIG. I

Fig. 1.

that the amphibolites may belong lower in the series than the limestone and quartzite.

The folding within the Grenville rocks was not worked out completely. If an outcrop is examined in detail, it is found that the rocks are tightly folded, and the limbs of the folds show the crenulations found in many of the rocks in the Grenville sub-province of the Canadian shield. The axial planes of most of the folds are vertical and strike a few degrees west of north near the contact with the quartz diorite. To the west, the axial planes of the folds tend to dip steeply east. The strike of the axial plane of the foliation may be taken as approximately parallel to the strike of the beds.

MASSIF OF QUARTZ DIORITE.

The quartz diorite massif is much smaller than that of granite, but several bodies of the same type are found in the district about Rivière à Pierre. All the bodies of it appear to follow the structure of the enclosing Grenville rocks, but as will be shown later they tend to cut across them to some extent. The outlines of the Rivière à Pierre body have not been completely traced, but it is about one mile and a half east and west and is over five miles long. Its extension to the north is cut off by a fault, which also displaces the contact between granite and Grenville rocks. The fault is marked by a steep north-facing escarpment of quartz diorite, and the fault probably follows the valley of Rivière Blanche just east of the part covered by the sketch-map, Fig. 1. Very large bodies of quartz diorite of similar appearance are known to the west, and several smaller ones occur near that here described. One is only a few hundred feet long and a few tens of feet wide. Another has very sinuous outcrops but extends for only a short distance on the surface.

Petrography. The rocks of the massif are all medium grained. They show some differences in appearance from place to place because of the variable proportions of the dark minerals. The differences are not so great as might appear at first sight, but the dark minerals are between 30 and 40 per cent of the whole rock. All the specimens show a marked foliated[2] structure.

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[2] I use foliation here as a general term to cover platy parallelism of minerals and parallel banding in igneous and metamorphic rocks. If examined very closely, most granites show both structures but to various extents. The quartz diorite described here has foliation well developed. The quartz syenite at Rigaud, Quebec, is almost devoid of such structures. Little alignment of the platy minerals can be found, and the rock abounds in irregular vugs, into which crystals of the rock minerals project. In the foliated rocks the material to form such vugs was expelled, but in the rock from Rigaud the deformation was not sufficient to expel the pegmatitic residue.

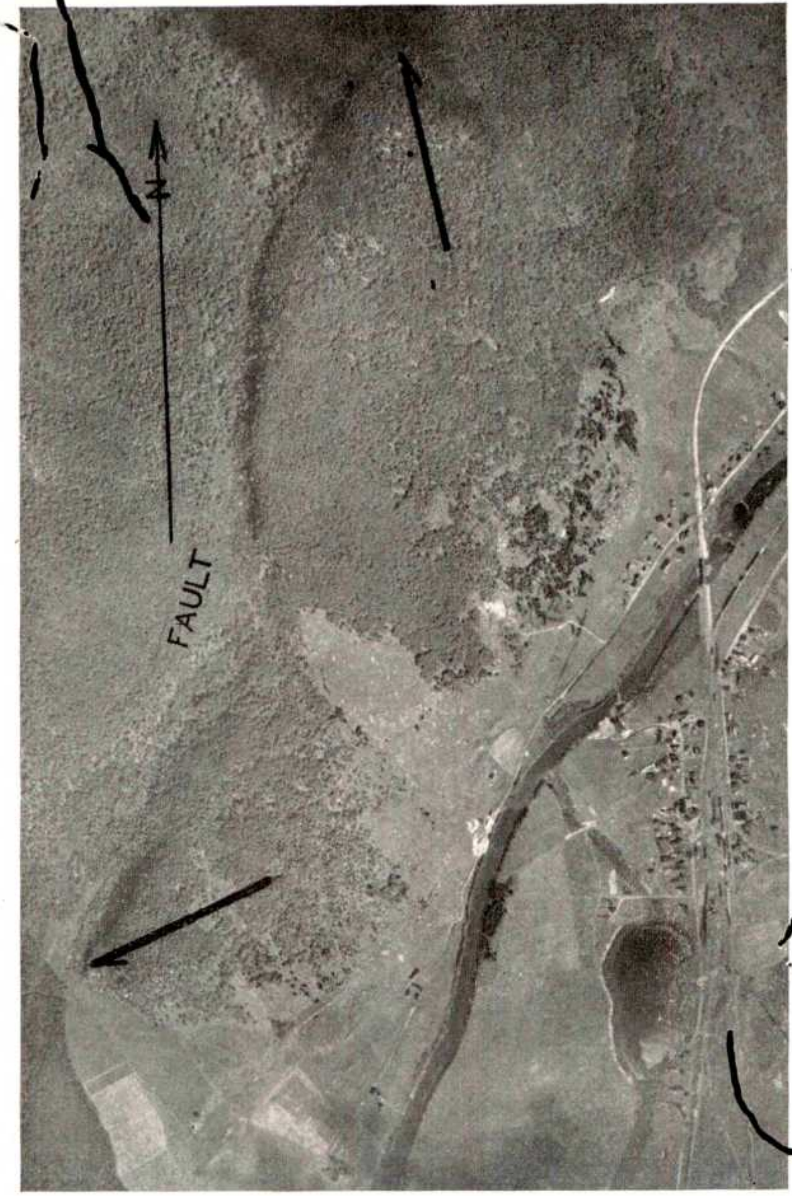

Fig. 2. Heavy arrows indicate north and south corners of quartz diorite against fault. *Royal Canadian Air Force Photograph.*

The microscope shows, in order of abundance, plagioclase feldspar, quartz, biotite, hornblende, epidote, titanite, apatite, and zircon. The gneissic structure is clearly seen under the microscope in sections cut at right angles to the direction of foliation.

The feldspar is near An$_{30}$ in composition, and in some of the rocks the zoning does not exceed five mol per cent anorthite; in others, however, a zoning over a greater range is seen. The larger individuals of feldspar show very faintly-defined lamellae of polysynthetic twinning along the margins or no twinning whatever. In vertical sections cut at right angles to the direction of foliation (the "hardway" section), the plagioclase is seen to be in ovoids about 7 mm. long in the plane of foliation and 5 mm. at right angles thereto. In this section the feldspar shows nearly central emergence of the bisectrix α. The ovoids are surrounded by grains of plagioclase of the same composition as that composing the ovoids, but the grains are only 2 mm. in diameter. A few of the small grains are nearly in parallel orientation with the feldspar of the adjacent ovoids, but most of them have some other orientation. All of the small grains have well-developed albite and pericline twinning lamellation, and the cleavage cracks are more noticeable in them than in the feldspar of the larger grains.

The quartz is in anhedra a trifle larger than the small grains of plagioclase. Some of the quartz appears to cut the ovoids and to lie between the small grains of the plagioclase, but the quartz is not elongated into vein-like masses such as are found in some protoclastic rocks.

The biotite is in flat tabular crystals of about 7 mm. diameter and tends to form clots, which may include some of the hornblende. The latter is in needles about 8 mm. long, which lie in the plane of the foliation. It is a common green variety with a pleochroism of $\alpha =$ olive-green, $\beta =$ blue-green, and $\gamma =$ blue-green. The extinction angle, $\gamma \wedge c$, is 25°. Epidote occurs in more than inconsiderable amounts in all the slices of this rock examined. In some parts of the massif almost 5 per cent of epidote is found and, except for the commonly accepted notion that epidote is a secondary mineral, the mineral would be interpreted as primary. It is commonly associated with the biotite or at the contact of dark minerals and plagioclase. Apatite, titanite, and zircon are the accessory minerals. Opaques are absent. Where enclosed in biotite or hornblende the zircon but not the titanite is surrounded by pleochroic halos. The rock, which has the appearance one associates with a typical quartz diorite, is somewhat unusual in that the plagioclase, as nearly as may be determined, is on the line between oligoclase and andesine. Commercially the rock is known as a "blue-grey" granite, and I would prefer the name granite except for the resemblance to the quartz diorites characterized by the more calcic feldspar. The content of dark mineral is too great for the rock to be called a trondjemite, and the considerable content of hornblende makes tonalite an equally unsuitable name.

Origin of the texture of quartz diorite. The texture of the rock is largely the result of movement in the magma during its crystallization. The ovoids of plagioclase are the relics of large crystals, which were mashed along the margins to yield the aggregate of small grains. In these rocks the development of polysynthetic twinning and perhaps cleavage may be attributed to the deformation. The dark minerals appear to form lenticular aggregates lying in the plane of foliation. In some places the clots detract very much from the appearance of the stone for monumental purposes, but elsewhere, they are only noticeable under the microscope. The large crystals of plagioclase may have made the rock sufficiently unyielding to prevent the quartz from being more drawn out. The epidote is, perhaps, to be considered as a *stress mineral* developed in the rock as a result of the deformation, and is probably a primary mineral. Some of the anomalous structure described later may be due to stresses from the nearby granite massif, but the epidote is found in the quartz diorite miles from granite.

Structural relationships of the quartz diorite. The quartz diorite shows a number of interesting, and several anomalous, features in the relationships of its structures to those of the enclosing Grenville rocks and in its textures.

The rift[3] in the quartz diorite is not a primary structure, but is determined by cracks that follow lines of minute inclusions in the quartz and pass into the adjacent minerals. The rift is approximately horizontal and is not found everywhere in the massif. In some places *at the lower levels* of the hills and along the river, the rift cracks are lacking; furthermore, although the rift is approximately horizontal, it is found to be related to the topography, in that it slopes in the same direction as, but commonly much less steeply than, the hillside under observation. Near the centres of some large hills the rift is nearly horizontal. These observations suggest that the minute inclusions, which appear to localize the fracturing, are the result of tension normal to the plane in which they lie: the rocks are under lateral stress and the relief of pressure and thus the direction of tension is vertical. The unequal removal of the rocks over hills and valleys may account for the deviation of the rift from horizontality.

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[3] The *rift* is the direction in which the stone may be broken along a relatively plane surface with the greatest ease. The *grain* is the direction approximately at right angles to the rift along which the stone breaks less readily. The third direction approximately at right angles to the other two is known as the *hardway* or *head*.

The quartz diorite has the same granularity right to the contact with the Grenville rocks, but at the contact, it has a slightly greater content of the dark minerals. The strike of the foliation in the massif under consideration is rather constant and is about N35°W. The dip of the foliation is much less constant: near Rivière à Pierre it is from 45° to vertical. Close to the eastern contact with the Grenville rocks, the dip is 60°W, but on the west it is 75°E, and between it is vertical. South of Rivière à Pierre the strike of the foliation, aside from one sharp bend, is about the same as it is near Rivière à Pierre, and the dip is about 50°E.

Near the quartz diorite Grenville contact, which strikes N20°W, the quartz diorite has many inclusions of the grey paragneiss of the Grenville series. The inclusions are small and are certainly not connected in any way with the country rock; they show the same direction of foliation as do the adjacent Grenville rocks, and that direction is inclined to the foliation in the quartz diorite and also to the direction of the contact between quartz diorite and Grenville. See Fig. 3. Where this structure was observed in detail, the strike of the foliation of the quartz diorite is N35°W, the strike of the foliation of the Grenville is N5°W, and the direction of the contact is N20°W. The direction of elongation of the inclusions is also the direction of an obscure foliation in the rock inclined at a small angle to the more marked foliation. In some quarries the stone has been worked along this false-grain instead of along the foliation.[4] The result is that polished surfaces in all directions except the grain show a very pronounced "run" of the foliation.

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[4] Sander, Bruno, Gefügekunde der Gesteine, p. 218, Vienna, 1930.

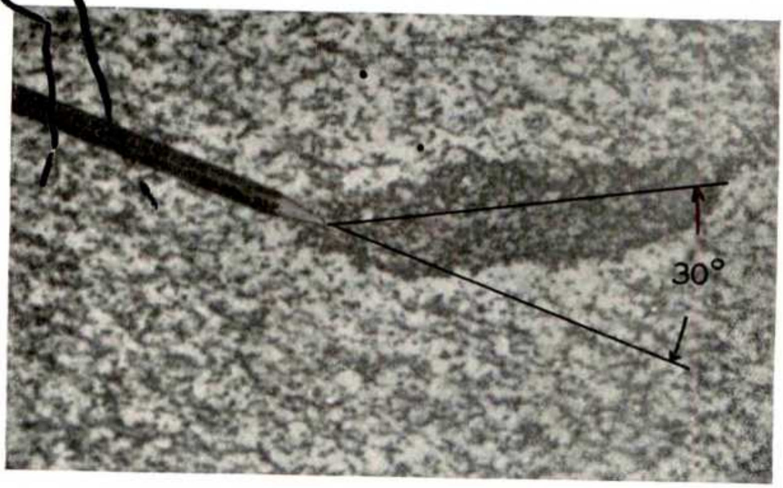

Fig. 3. Black clot on quartz diorite in horizontal (rift) section. The foliation is along the pencil. The grain as worked is parallel to long axis of clot, but stone breaks out from feather holes parallel to the foliation. Inclusions of Grenville rock have same orientation as clot.

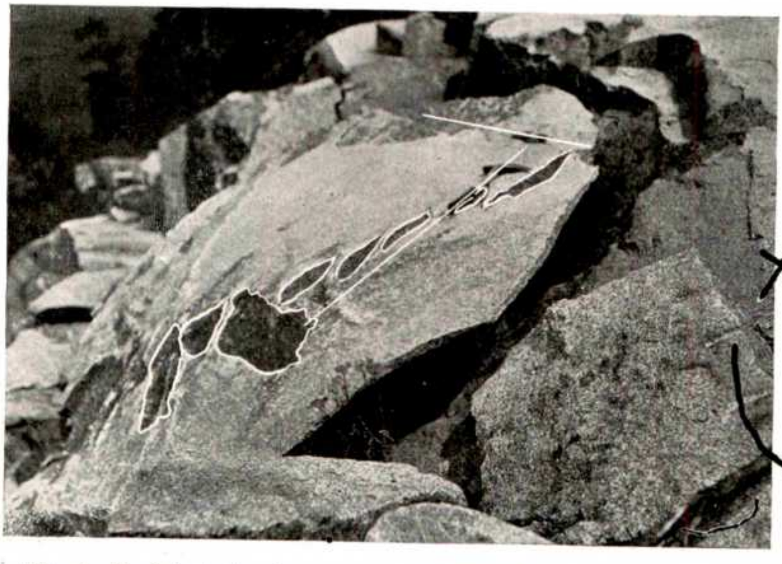

Fig. 4. Dark inclusion drawn out in direction of hammer handle. Trace of foliation is in direction of white line at top. The angle between the two directions is much exaggerated by the camera.

The quartz diorite has several other features that appear to be different from those developed within the granite. The contact-metamorphic effects of the quartz diorites are slight, except for some granitization of the amphibolites. Feldspar is a characteristic mineral of the metamorphism. Epidote, which is found close to the granite, is absent in the country rock. The quartz diorite and adjacent Grenville rocks are cut by many dykes of pegmatite and aplite. Some of these follow the direction of foliation. There are also mafic dykes about one-quarter inch wide which run in the direction of the false-grain. In one place near the middle of the band of quartz diorite an irregular inclusion, now an aggregate of biotite and hornblende, has been deformed and lenticular pieces of it separated and moved along the pseudo-foliation. The true foliation is inclined to the latter at a considerable angle as shown in Fig. 4.

GRANITE MASSIF.

The granite at Rivière à Pierre is part of a large massif. The body is known to extend at least 20 miles east of Rivière à Pierre although interrupted by several large foreign inclusions, and for at least 20 miles north. No attempt was made to trace the boundaries of the body, but so far as known, the very coarse grain characterizes the whole of it. The western contact of the massif is almost a straight line. It is marked by the valley along which the Canadian National Railway line to Lake St. John runs from Rivière à Pierre to the Batiscan River. The strike of the contact is N30°W, and the contact itself is so straight, except where it is offset by faults, as to suggest that the granite was intruded along a fault. The fault preceded the intrusion of the granite, for the latter shows a chilled zone along most of its western boundary in the area covered by the sketch map, Fig. 1.

Petrography. The western margin of the massif is marked by a zone of granite of medium granularity, from 500 to 1,200 feet wide. The zone is, in part, covered by drift, but its position is shown by the heavy diagonal hatching of Fig. 1. This zone is interpreted as a chilled facies formed against a relatively cool country rock. It is noteworthy that the chilled zone contains many fragments of the paragneisses, and the foliation, which characterizes the rocks of the zone, bends around them. The intrusion of the magma into a cold country rock would be a favourable circumstance for stoping, thus accounting for the numerous fragments. In contrast with those in the quartz diorite most of these inclusions are equidimensional, and the tabular ones have not been brought into a rigorously parallel arrangement such as has been imposed upon those in the quartz diorite.

The granite of the contact zone is medium-grained and pink, but is somewhat mottled in appearance. Under the microscope it is seen to have a panallotriomorphic texture. Microcline with the characteristic *moiré* structure is the principal mineral. It has been replaced and embayed by albite-oligoclase, which contains "tear-drops" of quartz, giving myrmekite. The crystals of slightly more calcic plagioclase have no quartz associated with them and do not appear to have replaced microcline. The quartz of the rock is biaxial, and although it does not show strain shadows, a faint grid structure is seen in basal section under crossed nicols. This phenomenon is perhaps the result of strain. The mafic mineral is a strongly-absorptive brown biotite. Hornblende, which is the characteristic mineral of the coarse facies, is lacking in the thin sections studied from this zone.

In places the granite of the contact zone forms inclusions in and is cut by the normal coarse granite of the massif, but elsewhere, it grades into the coarse facies. The prevalent facies of the granite is very coarse-grained with coloured microcline as the dominant mineral. In some places the microcline is pink, in others it is pale mauve, and elsewhere a deeper mauve. The crystals may be as large as 40 mm., and a diameter of 20 mm. is common. The plagioclase is less uniform both in size and color than the microcline. A pale mauve idiomorphic crystal 70 mm. long was observed in one quarry, but most grains are smaller than those of microcline. In the slices of the rock examined, the plagioclase is oligoclase, and the crystals show their own outline against the microcline and quartz. Part of the microcline has been replaced by myrmekite. The quartz is in stringers and strain shadows are common. The dark minerals are green hornblende and green-brown biotite. Zircon, titanite, and apatite are accessory minerals. A uniaxial carbonate is found in veinlets in the microcline, and calcite, epidote, prehnite, quartz, and pyrite occur in joints in the rock.

Pseudo-pegmatite fringes. A quarry in the coarse facies of the granite just north of Rivière Blanche shows interesting and unusual structures about some rounded inclusions of the marginal facies. These are fringes of coarse feldspar seen on one or both sides of sections of the inclusion. If the fringe appears on one side only, the opposite side may be enriched in crystals of the dark minerals. At first sight the fringes appear to be due to the injection of pegmatitic material along a plane of weakness between the two facies of the granite, but close inspection shows that such a hypothesis is untenable. The large crystals of feldspar appear to be the result of a free growth about the inclusion as it was suspended in the magma, and thus of early rather than late crystallization. The structure was observed in quarried blocks in both horizontal (rift) sections and vertical (grain) sections, but it was not possible to determine which was the top and which the bottom. The example pictured in Fig. 5 has not the coarsest or widest fringe observed. Those of asymmetric type are shown in the vertical sections, although all vertical sections are not asymmetric.

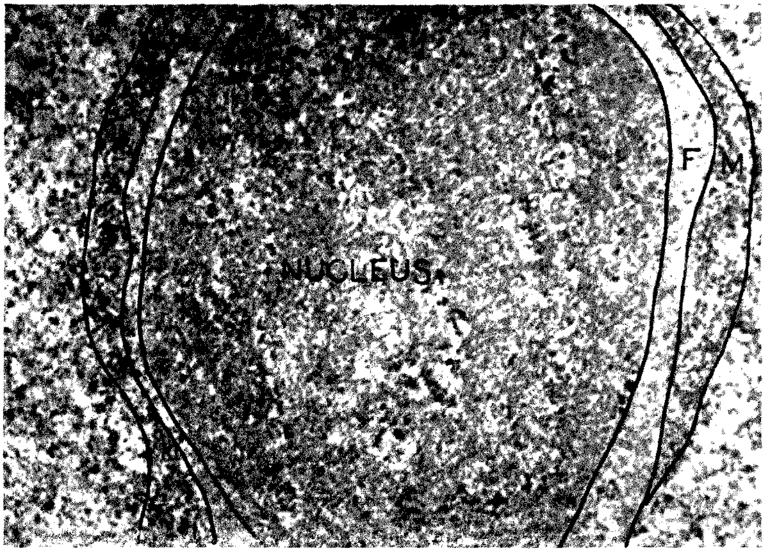

Fig. 5. Feldspathic rim (F) around inclusion in granite. (M) is band more rich in mafic minerals. Horizontal (rift) section.

Several hypotheses of origin might be suggested to account for the fringes. The fragment of the chilled zone might have seeded the magma and allowed the large crystals of feldspar to form. Such a relationship receives some support from the fact that fringes were not observed about inclusions of paragneiss in the same quarry. It is possible, however, that the inclusion of the chilled zone simply acted as a support for the growing crystals. Nuclei of feldspar might rise in the magma to attach themselves to the bottom of the inclusion and grow, while nuclei of the dark minerals, sinking against the top, would crystallize there. This would give the vertical asymmetrical fringes. In the symmetrical fringes the inclusion may have been rotated in the magma and allowed both light and dark minerals to become attached on all sides. The presence of the fragments of the chilled zone is perhaps due to the similarity in density of rock and magma. The inclusions of the more mafic gneiss sank into the magma more readily and probably those left at any level are later than the neighboring inclusions of the border facies.

There is little doubt that the fringes are the result of slow cooling under quiet conditions. Similar fringes were later found in some of the older gneisses of the Laurentian area about inclusions of amphibolite and were used as evidence that the gneiss was of igneous origin.

Structural relationship of the granite. The several large quarries within this granite have made it advisable and possible to make observations on the orientation of the structures of the granite within the area covered by the accompanying sketch map.

The rift is approximately horizontal, as it is in most Quebec granites. It is defined by cracks spaced about 1 mm. apart in the quartz. The rock is so coarse that the cracks are very easily seen and resemble cleavage cracks, but are independent of the orientation of the quartz grains through which they cut. The cracks extend into the adjacent feldspar, but tend to be deflected along the cleavage directions. The rift is much better than that in the quartz diorite, and it tends to have the same direction of slope as that of the hillside on which the quarry is situated. It is believed that the rift is developed in the direction normal to the effective tension. The rift of the "black granite" of Mt. Johnson, which is an essexite, is vertical and in the plane of foliation. This is an exceptional arrangement among Quebec granites; in most quarries the foliation, which brings the 010 cleavage of feldspar and the cleavage of some mafic minerals parallel to one another, coincides with the grain.[5]

In a few quarries at Rivière à Pierre a vertical cracking similar to the horizontal rift-cracking is found in the quartz and determines a direction of grain at right angles to the foliation. The direction of the foliation, then, is the hardway. It is not that the stone breaks less readily along the foliation in these quarries than in those in which the foliation coincides with the grain, but the stone breaks less readily along the plane of stretching than along the direction of the vertical cracks in the quartz. In general, however, the direction of the foliation coincides with the grain, and the grain is, therefore, a primary structure indicating the planes of shear set up by movement in the partly crystalline magma. The direction of foliation is found to be inconstant in the area under consideration. The strike of the foliation in the chilled zone close to the granite-Grenville contact is irregular and tends to follow minor irregularities in the direction of contact. Inside the chilled zone, the strike of foliation is inclined to the direction of contact, and the strike is more toward the northeast the farther east one goes of the contact between Grenville and granite. The strike of foliation is fairly consistent over restricted areas, and the swing of the strike is so gradual that the change is noticed only where careful measurements are made.

A very marked change in the direction of strike takes place near a vertical inclusion 2,000 feet long and 300 feet wide in the northern part of the area covered by the accompanying sketch map. The strikes of the foliation on the two sides of the inclusion are about 30° to one another and about 15° to the elongation of the inclusion. Flat, sill-like inclusions are found on the eastern side of the area.

Despite the inconstancy of the strike of the foliation, the strikes of the joints, other than those followed by the dykes of pegmatite and aplite, are fairly consistent throughout the area examined.

The straightness of the western contact against the Grenville rocks suggests that the magma may have come up along a fault. In its advance the movement was not simple, but the crystals and magma were of such rigidity that the resulting rock was foliated in a direction inclined to the contact. It is possible that the magma spread east horizontally, but further observations are required to check this.

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[5] Probably the grain is in the plane of alignment of constituents of most commercial granites, for an experienced stonecutter in explaining his use of grain said, "You can see it: it is like the grain in wood."

The contact alteration brought about by the granite is quite different from that attributed to the quartz diorite. The granite altered the intrusive rocks to epidote and brought about considerable recrystallization without the production of foliation. One inclusion studied in thin section is an aggregate of andesine, augite, and hypersthene and resembles some facies of the rocks of the anorthosite series.

Relative ages of the two massifs. No inclusions of either plutonic rock were noted in either massif, although inclusions of foliated and unfoliated rocks of the Grenville series are numerous in both. It is believed, however, that the quartz diorite is the older. At Rousseau Mills, 10 miles west of Rivière à Pierre, a coarse porphyritic granite cuts quartz diorite and a contained aplite dyke. The granite resembles certain rare facies in the chilled zone of the massif described here. The granite is, therefore, considered to be younger than the quartz diorite, and this conclusion agrees with the rule applied in the Canadian pre-Cambrian that the pink coarse granites are younger than the grey foliated granites.

Comparison of the quartz diorite and the granite. The quartz diorite was intruded during the deformation of the surrounding Grenville rocks and its marked gneissic structure resulted. The crystals of plagioclase were inequidimensional, and they were brought into alignment with some granulation of the margins of the grains. The dark minerals escaped the effects of the stress as also did the quartz. The epidote may have been formed as a stress mineral as a result of *Piëzokrystallisation.* The quartz diorite did not form a chilled zone against the country rock, either because the wall was warm or, more probably, because the movement of the magma broke it up as fast as it was formed. The intrusion of the granite, on the other hand, took place with less stress than did that of the quartz diorite. The magma advanced along the fault line and formed the chilled zone against the Grenville. This chilled zone was instoped by the advance of the same magma, and pseudopegmatitic fringes were formed around some of the inclusions as they were suspended in the magma. After the magma was crystallized to a considerable extent, the mixture would stand a shearing stress, and the foliation was formed in a direction not controlled entirely by the direction of the contact. It is possible that this shearing stress exerted by the magma was sufficient to bring about some rearrangement of minerals in the Grenville rocks and in the quartz diorites so as to produce some of the anomalous structural relationships found in the quartz diorite.

The quartz diorite is cut by many dykes of pegmatite and aplite, and but few are found in the granite. The quartz diorite brought about granitization of the surrounding Grenville rocks, possibly due to the material expelled during deformation. The granite, on the other hand, caused a metamorphism that resulted in the formation of a massive rock with the production of epidote and quartz. A simple jointing rather than a gneissic banding was produced.

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THE ORIGIN AND AGE OF THE BOULDER-BEARING JOHNS VALLEY SHALE IN THE OUACHITA MOUNTAINS OF ARKANSAS AND OKLAHOMA.

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The Johns Valley shale is a dark clayey shale, locally some 1,000 to 1,500 feet in thickness, that occurs in the upper part of the geologic section of the northern and western Ouachita Mountains in west central Arkansas and southeastern Oklahoma. Its most distinctive character is the occurrence of numerous large and small boulders distributed irregularly through the shale. Since the boulders are identifiable as having been derived from fossiliferous Early, Middle and Late Paleozoic formations that are foreign to the Ouachita stratigraphic section and since some of the boulders have a maximum diameter measured in hundreds of feet, the origin of the Johns Valley beds is an exceptionally interesting problem. The age of the boulder-bearing shale is likewise a subject that has given rise to much discussion, for some evidence seems to indicate definitely a Late Mississippian age while other evidence quite as definitely supports the conclusion that the deposit is of Early Pennsylvanian age. Study of the Johns Valley shale has importance, therefore, not only because it is an unusual type of sedimentary deposit but because determination of the origin and age of the formation is believed to have bearing on the location of the Mississippian-Pennsylvanian boundary.

My first field study of the Johns Valley boulders was made in the summer of 1927 in company with H. D. Miser of the U. S. Geological Survey. During part of the time then spent outcrops in Johns Valley, north of Antlers, and Compton Cut, north of Talihina, both in Oklahoma, were visited with H. D. Miser, Sidney Powers, C. W. Tomlinson, C. N. Gould and C. L. Cooper. Papers describing the boulders and discussing their origin had previously been published (as noted in the appended bibliography) by Taff (*11, 12*), Woodworth (*19*) and Ulrich (*14*). Subsequent to 1927, contributions to study of the problem have been written by Miser (*8, 9*), Powers (*10*), Van der Gracht (*15-17*), Harlton (*5*) and more incidentally by others. In August, 1932, Mr. Miser and I revisited Johns Valley and spent two days studying the numerous scattered boulders and outcrops of boulder-bearing shale that had recently been discovered near Boles, Scott County, Arkansas. Special acknowledgment and appreciation are due to Mr. Miser for this assistance. On various occasions I have discussed the boulder problem with Miser, Powers, Harlton, Tomlinson, Ulrich, and A. I. Levorsen, and I express thanks to them for aid in the study. Until recently, however, I have not been able to formulate an explanation that seemed to me to fit reasonably with field observations.

THE JOHNS VALLEY SHALE.

The Johns Valley shale was named in 1927 by Ulrich (*14*, p. 21). The shale in Johns Valley (Ts. 1 N. and 1 S., R. 16 E., Oklahoma) and equivalent outcrops in the Ouachita Mountains area had previously been called Caney and for some time had been regarded as equivalent to the fossil-bearing marine shale of Late Mississippian age, likewise called Caney, on the north and south flanks of the Arbuckle Mountains. Fossils exactly like those of the Arbuckle Caney were known to occur commonly in the Ouachita "Caney" shale. The shale of the Arbuckle area, however, was observed to be entirely lacking in erratic boulders while that of the Ouachita region contains them abundantly. Indeed, "Caney" (now called Johns Valley) with boulders occurs in many places just south of the Ti Valley fault that parallels the northwest front of the Ouachitas, whereas on the other side of this fault only a short distance away are outcrops of boulderless Caney of the Arbuckle type. Evidently, the difference in content of boulders is significant but the identity of marine faunas in the two shales seemed certainly to indicate equivalence in age. Ulrich called attention to actual slight differences in the lithology of the shales and concluded that the Caney fossils of the boulder-bearing "Caney" were all reworked (*14*, p. 19). Like the boulders which had been derived from various older formations, Ulrich interpreted the fossils as having been transported from their original place of burial in Arbuckle Caney shale and redeposited in the younger Ouachita "Caney" shale. Believing that the two shales were entirely different, it naturally became desirable to rename one of them. Since the term Caney was very well known and commonly applied in the Arbuckle section, the new name Johns Valley shale was proposed for the boulder-bearing shale in the Ouachita Mountains. It was regarded by Ulrich as Early Pennsylvanian in age.

General Character and Distribution.—Because of previous publications it is unnecessary to give here a detailed description of lithologic features of the Johns Valley shale. It is sufficient to say that, although dark grey to almost black like the Caney, the Johns Valley beds are mostly distinguishable on lithologic characters from the Caney. The latter formation is harder, more distinctly and evenly laminated, less unctuous when wet and a little darker in general tone than the Johns Valley shale. Studies by Harlton (5) of the microfaunas from numerous typical Johns Valley outcrops show definite, easily perceptible distinctions in the fossils from this formation and those found in the Caney as restricted. On the other hand, there are exposures of shale in parts of Johns Valley and near Boles, Arkansas, in the Johns Valley outcrop belts, that duplicate in every known feature of lithology and fauna the characters of typical Caney shale of the Arbuckle region. These evidently conflicting observations are responsible for much of the confusion connected with descriptions and interpretations that have been published. The significance of the divergent evidence will be discussed later.

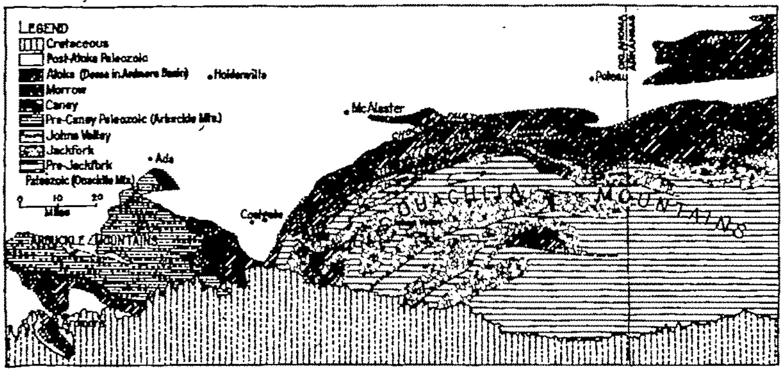
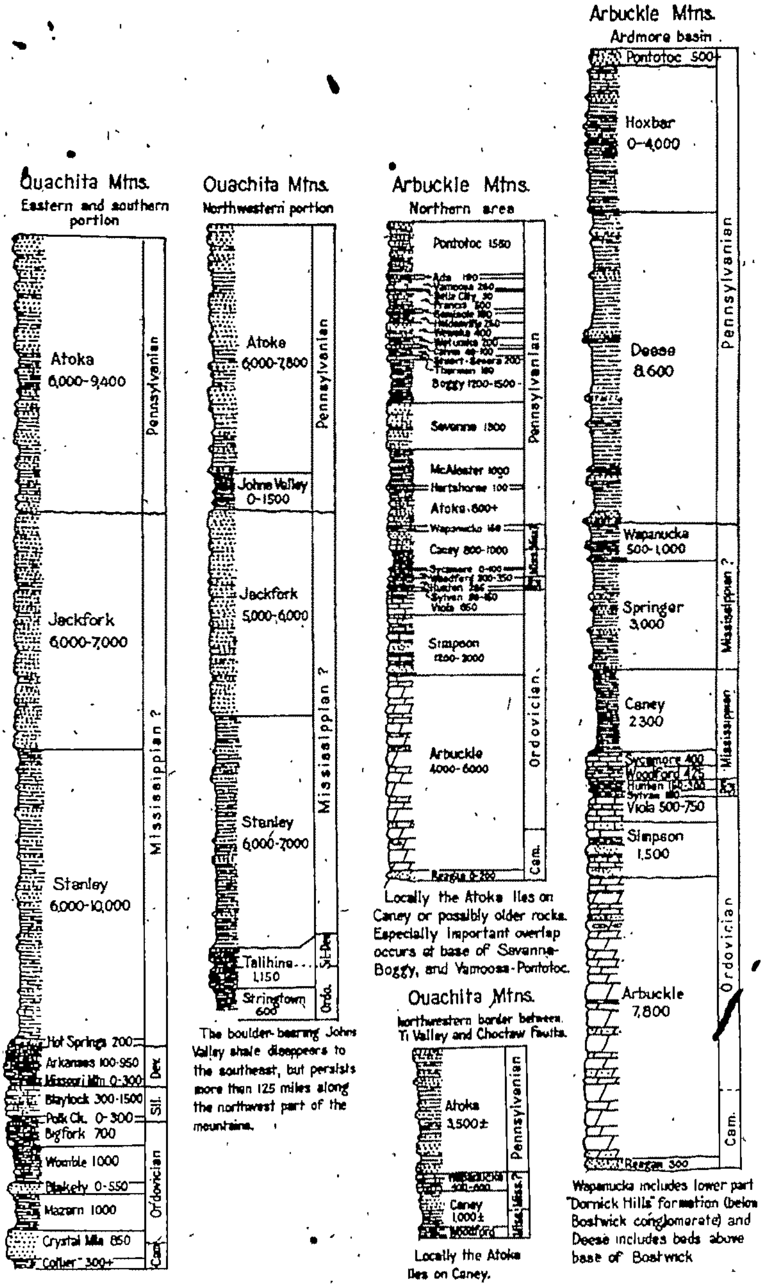


Fig. 1. Map of the Ouachita and Arbuckle region showing distribution of Johns Valley and Caney shales.

Distribution of the boulder-bearing Johns Valley shale and of the Caney shale is shown in the accompanying map (Fig. 1). The known extent of the deposits along the strike of the outcrop belt from the line of concealment by Cretaceous overlaps on the southwest to the farthest known occurrence on the east, is about 130 miles. The maximum distance from the outermost to the innermost outcrop belt at right angles to the average strike is about 14 miles, but if shortening due to folding and faulting were removed this maximum distance would probably be expanded to upwards of 20 miles. The exposures of boulder-bearing shale are all located southeast of the Ti Valley fault. For reasons subsequently developed, I would restrict application of the name Johns Valley to this region, excluding belts of dark shale north of the Ti Valley fault that were regarded by Ulrich (*14*, p. 13) as equivalent to Johns Valley shale.

Stratigraphic and Structural Relations.—In each known occurrence the Johns Valley shale rests with parallel structure, so far as known, on Jackfork sandstone. The latter is a very competent formation, 4,000 to 6,000 feet or more in thickness, consisting of massive beds of quartzitic sandstone separated in places by layers of shale a few tens of feet in thickness (Fig. 2). The Jackfork rests with apparent conformity in turn upon the Stanley shale, 6,000 to 10,000 feet in thickness. The Stanley consists mainly of dark, somewhat greenish shale, but contains many layers of dark-greenish sandstone, the latter increasing in numbers and thickness toward the southeast. The Stanley is a relatively incompetent formation. Scanty and poorly preserved marine fossils and plant fossils that have been collected from the Stanley and Jackfork formations indicate definitely their "Carboniferous" age, but whether either or both belong to Late Mississippian or Early Pennsylvanian time has been entirely unsettled, although there has been a growing tendency to regard the Stanley as Late Mississippian (Chester). Some geologists regard the Jackfork also as Late Mississippian, but others think it may be better interpreted as an initial Pennsylvanian deposit resulting from uplift of the hinterland south of the Ouachita geosyncline. The uplift is thus regarded as forming part of the crustal changes that may be inferred to have terminated Mississippian sedimentation and introduced Pennsylvanian conditions (see Ulrich, *14*, p. 23). A review of paleontologic and other evidence on the age of the Stanley and Jackfork formations has been published by Miser and Honess (*8*).

In most exposures the boulder-bearing Johns Valley shale occurs between Jackfork sandstone, which extends continuously beneath it, and sandstone and shale of the Atoka formation, which continuously overlies it. In the eastern and southern parts of the Ouachita Mountains area, Atoka beds rest



The boulder-bearing Johns Valley shale disappears to the southeast, but persists more than 125 miles along the northwest part of the mountains.

Locally the Atoka lies on Caney or possibly older rocks. Especially important overlap occurs at base of Savanna-Boggy, and Vamoosa-Pontotoc.

Ouachita Mtns.
northwestern border between Ti Valley and Choctaw Faults.

Locally the Atoka lies on Caney.

Wapanucka includes lower part "Dornick Hills" formation (below Bostwick conglomerate) and Deese includes beds above base of Bostwick

Fig. 2. Generalized sections of rocks in the Ouachita and Arbuckle areas.

directly on Jackfork sandstone, but it is significant that throughout the known area of Johns Valley occurrence along the northwestern margin of the Ouachitas the boulder-bearing shale is found in a constant stratigraphic position between Jackfork and Atoka. This observation is important.

At the type locality in Johns Valley, the boulder-bearing shale occurs in a comparatively broad gentle syncline of elliptical form underlain by Jackfork sandstone which forms a rim surrounding the valley. A small area of Atoka beds in the central part of the syncline is shown on the state geological map of Oklahoma compiled by Miser (1926), but subsequent studies by Miser indicate that the sandstones here found are upper Jackfork which is brought to the surface by minor anticlinal folds in the syncline. Farther south there are similar broad synclinal folds involving Jackfork, Johns Valley and Atoka beds which, however, are intersected by thrust faults that cut across the axes of the synclines. Along the northwestern and northern Ouachita front the Johns Valley and associated rocks are steeply inclined, the outcrops being variously repeated as a result of folds and thrust faults.

Erratic Boulders.—The erratic rock fragments in the Johns Valley shale range in size from small pebbles to masses 369 feet[1] or more in greatest diameter (Miser, *9*, p. 28). Most common are boulders of various sorts of limestone, but there are also masses of chert, sandstone and, according to Harlton's (*5*, p. 5) view and mine, of shale. Some of the limestone and chert boulders are peculiarly scratched, grooved or gouged.

Many of the boulders contain fossils, and it is possible by means of these and by observation of distinctive lithologic features to identify the geologic formations that supplied the boulder material. Ulrich (*14*, pp. 9-21) has demonstrated that the source beds of the boulders range in age from Cambro-Ordovician (Arbuckle) to so-called Early Pennsylvanian (Wapanucka or Morrow).[2] Especially common are boulders of Arbuckle and Simpson limestone. These and many other of the boulders correspond so closely to well-known formations of the Arbuckle Mountains area that Ulrich (*14*, pp. 13, 44) concludes that this region was undoubtedly their source. It is certainly significant that the formations represented by the boulders are entirely foreign to the Ouachita geosynclinal area, in which the formations corresponding in age to that of the boulders are entirely different. That the boulders were not actually derived from the existing Arbuckle Mountains area is, however, indicated by absence of Johns Valley type of boulder-bearing shale in any part of the Arbuckle Mountains region, and by the occurrence among the boulders of fossiliferous Devonian chert closely resembling the Camden chert of Tennessee, but absent in the Arbuckle Mountains district. As noted by Ulrich (*14*, p. 19), however, a small outcrop of cherty beds containing this fauna occurs at one locality at the northwest margin of the Ouachita Mountains, just north of the Ti Valley fault. Many of the boulders observed near Boles, Arkansas, resemble units known in the Ozarks more closely than any formations in the Arbuckle Mountains. Among these Ozark-type boulders, Miser has discovered a fossiliferous fragment of Boone (Middle Mississippian) limestone containing fossils. The Boone is entirely unknown in the Arbuckles, but extends an unknown distance southward from the Ozarks toward the Ouachitas.

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[1] The record by Powers (*10*, p. 1043) of a boulder 550 feet in diameter is based on erroneous field determinations by Charles Miller and is not to be credited.

[2] Miser notes that the Wapanucka-like rocks seen by him in the Ouachitas are in the form of beds or broken beds. This has important bearing on the age of the Johns Valley shale and calls for further study.

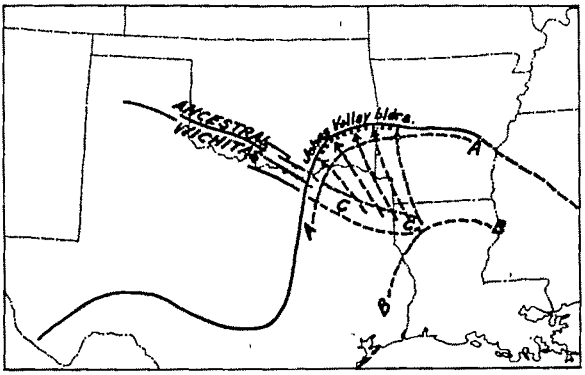

Fig. 3. Sketch map showing relation of the Ouachita geosyncline to the Ancestral Wichita Uplift. The sinuous line extending across the map marks the present front of northwestwardly thrust Ouachita geosynclinal rocks. A-A marks the original northwest border of part of the geosyncline if crustal shortening due to the Ouachita orogeny amounts to about 50-75 miles. B-B marks this original border if the Johns Valley boulders were derived from an overridden southeastward extension of the Ancestral Wichita Mountains, C-C. The arrows indicate assumed movement of the boulders from this source according to the tectonic hypothesis.

Under the head of erratic boulders I may now refer to certain outcrops of black shale which are well shown in Johns Valley and near Boles, Arkansas. These outcrops of shale, which appear along small streams, have maximum linear extent of some hundreds of feet, and in one case an exposed height above the creek of more than 50 feet. The outcrops have commonly been interpreted as part of the Johns Valley shale matrix, which, despite the fact that these particular shale bodies lack any erratic boulders, has been presumed to be the same as the boulder-bearing shale elsewhere. As a matter of fact, the boulderless black shale masses are typical Caney shale of the Arbuckle type. The lithology of this true Caney shale

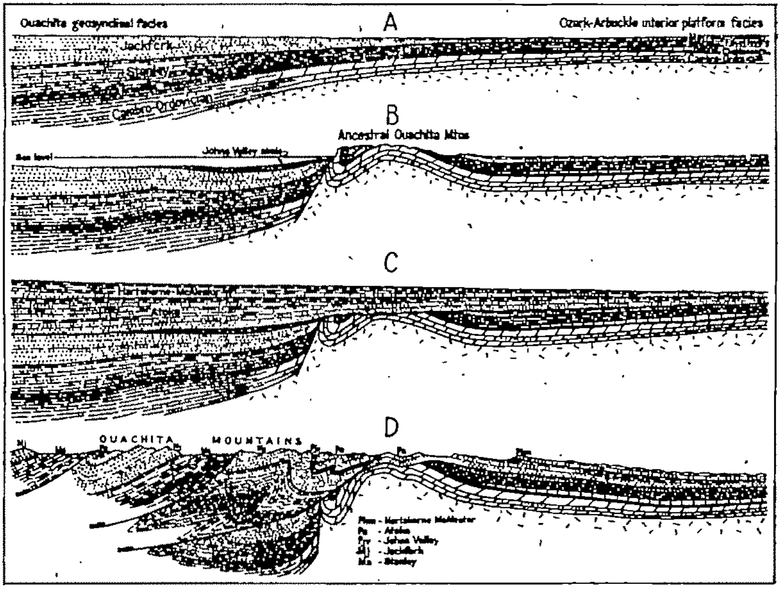

Fig. 4. Diagram showing inferred development of the Ancestral Ouachita Mountains along the northwest border of the Ouachita geosyncline. *A*. Section of the geosyncline and neighboring foreland near close of Morrow time. *B*. Same in Johns Valley time, showing hypothetical Ancestral Ouachitas and formation of the boulder-bearing Johns Valley shale which is here classed as basal Pennsylvanian. *C*. Same in post-McAlester time. The Ancestral Ouachita Uplift is represented as beveled by pre-Atoka and early Atoka erosion and buried by Atoka and younger Pennsylvanian sediments derived from the hinterland south of the geosyncline. *D*. Diagrammatic representation of present conditions showing formations of the geosynclinal area overthrust on the Ancestral Ouachitas and the foreland.

can be distinguished readily from adjacent outcrops of Johns Valley shale containing boulders. At the Johns Valley locality I found and was able to trace for several feet the sharp contact between Caney shale and contiguous boulder-bearing shale. As already noted, the typical Caney contains no erratic boulders and it yields abundant Caney fossils. The fossils occur in small phosphatic nodules, in large subelliptical limestone concretions, and between bedding planes of the shale. The fossils between bedding planes are in places very abundant, and include many perfectly preserved delicate thin shells of brachiopods, pelecypods and other forms. In every respect the observed features of lithology and occurrence of fossils duplicate characters observed in Caney outcrops of the Arbuckle Mountains area, and accordingly there is no reasonable room for doubt as to actual identity of these outcrops with typical Caney.

The statement has been made by Ulrich (*14*, p. 19) that slightly waterworn reworked Caney fossils occur in the boulder-bearing Johns Valley shale. This is undoubtedly true, for I, also, have seen reworked Caney fossils in undoubted Johns Valley shale. Ulrich has advanced the view, however, that all of the Caney fossils from Johns Valley outcrop areas are reworked, that they may not be considered as having "lived, died, and been buried in the shale" where they are now found. With this interpretation in mind, Miser (*8*, pp. 22, 23) and I examined the fossil-bearing shale outcrop in Johns Valley. This is an outcrop which I now identify as true Caney shale, no erratic boulders being associated with the fossil-bearing strata. That the fossils found in this shale did live, die, and become buried in the shale containing them can be affirmed most emphatically. Miser is right in his published statements on this point, but neither Miser's nor Ulrich's statements as to the indigenous character of the Caney fossils in the locality containing shale applies to all of the Caney fossils in the Johns Valley shale outcrop areas. In other words, I conclude that the Caney shale masses with their contained indigenous fossils are themselves erratic boulders. Harlton (*5*, p. 5) has also noted that these shale masses are entirely typical "Mississippian Caney" and he regards them as "boulders" transported bodily from some part of the previously formed "Arbuckle Caney." Because it is harder to imagine the occurrence of large shale masses transported an unknown distance into new surroundings and because the Caney shale, though somewhat more indurated, lithologically resembles the surrounding Johns Valley shale, it is not surprising that the Caney shale bodies in the Ouachita area should have been regarded as occurring in place.

There remains to be specially mentioned the occurrence in the Johns Valley shale of erratic material derived from Wapanucka or other Morrow beds. Identification of the Morrow rocks rests both on lithologic and paleontologic grounds, some of which have been described by Ulrich (*14*, p. 21). I have found *Marginifera* and bryozoans regarded as typical of the Morrow in erratic materials at Compton Cut north of Talihina, Oklahoma. The reworked Morrow and Caney fossil-bearing rocks in the Johns Valley shale support Ulrich's main contention that the Johns Valley formation is younger than Morrow and Caney. Miser regards the Wapanucka boulders, especially at Compton Cut, as portions of ledges which have been broken during folding and faulting.[8] If this interpretation is correct, at least part of the Johns Valley beds under discussion must be of Morrow age.

ORIGIN OF THE JOHNS VALLEY SHALE.

Previous Hypotheses.

Attempts to explain the Johns Valley boulders may be classed in two groups: (1) those that assign the origin of the shale and its contained "erratics" to agencies of sedimentation, and (2) those that call on tectonic forces as the primary cause of observed conditions.

Hypotheses of Sedimentary Origin.—The geographic distribution of the boulders, their occurrence promiscuously scattered about in marine shale and the presence on some of them of striae and gouges, led Taff (*11, 12*) to conclude that they were transported by ice from "mountains in the region now occupied by southern Indian Territory [Oklahoma] and northern Texas." He mentions the rounding of some of the boulders, implying action of glacial ice but ascribes the striations to work of shore ice and in part to slickensiding due to differential movement and abrasion of one boulder on another during the much later Ouachita orogeny. Woodworth (*19*) emphasizes the nonglacial origin of the scratches on boulders seen by him north of Talihina but accepts the hypothesis of shore-ice work to account for transportation of the boulders. Ulrich (see *19*, pp. 458-460) concludes that shore-ice work offers the only satisfactory explanation of the peculiarities of some of the striae and regards transportation by large icebergs as necessary to account for distribution of the boulders, including strongly striated large rock masses, in such areas of gentle structure as Johns Valley. He thinks (*14*, pp. 13, 44) that the source of most of the boulders was in the eastern part of the Arbuckle Mountains area, which necessitates the conclusion that currents floated the boulder-laden bergs at least 100 miles eastward in some cases. Ulrich (*19*, p. 460) agrees that the scratches on many of the boulders in places of steep folding, as at Compton Cut, are the result of movement during folding. Miser (*8*, p. 22; *9*, pp. 28, 29) believes that the boulders are ice-transported and says that "the large size of the icebergs and their acquisition of such huge masses of rock suggest valley glaciation in a region of tilted rocks with valleys perhaps several thousand feet in depth." After discussion of the "Caney" boulder problem at some length, Tomlinson (*13*, pp. 25-27) also concludes that transportation of the erratic blocks by ice is the most plausible hypothesis, but he offers evidence to show that the source of the boulders could not have been located in the Arbuckle Mountains area. Powers (*10*, pp. 1045, 1046) finds "no theory as to the source of the boulders fully satisfactory." After analysis and rejection of tectonic hypotheses, he is driven to accept tentatively the idea of floating or shore ice even though he recognizes nearly insuperable difficulties.

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[8] Personal communication.

Dixon (*3*, p. 344) notes the possibility of origin of the boulders in a long, high fault scarp containing a variety of Paleozoic rocks of Arbuckle type, the boulders being broken loose and transported to their resting place by "successive landslips from this scarp [that] slid out over the Caney shale collecting at its foot."

The evidence in favor of glacial hypotheses appears to consist (a) of striations and gouged markings on some of the boulders and (b) of the lack of known transporting agency other than ice to account for distribution of the erratic masses, especially the larger ones. Woodworth (*19*) submits convincing evidence, however, to show that the supposed glacial scratches are not glacial. This is particularly indicated by slickensiding and flowage that extend inward a short distance from the surface of the grooves and it is also strongly marked by the appearance of plastic yielding and by peculiarities of form of the scratches as may be seen in Ulrich's photographs (*14*, pls. 3-6). I agree with Van der Gracht (*17*, p. 705) that "these quite irregular scratches and deep short gouges are anything but glacial." As for the assumed transportation by ice, the difficulties of loading large rock masses upon or embedding them in the ice that is to raft them seem insuperable. No evidence of glaciation or even of cold climate at this time is known except that supposedly furnished by the boulders. If, therefore, the markings on the boulders cannot be accepted as glacial and if some adequate means of transportation other than by ice can be suggested, little is left to support the glacial hypothesis.

The hypothesis of derivation of the boulders from a fault scarp and distribution through the agency of creep or sliding is supported by several considerations discussed later. It is opposed chiefly by the considerable horizontal shifting of the erratics that must be assigned to creep.

Hypothesis of Tectonic Origin.—The tectonic hypothesis of the origin of the Johns Valley boulders has been developed chiefly by Van der Gracht (*17*), who regards the Ouachita structure as duplicating in essential respects the profoundly overthrust nappes of the Alps. Parts of the shale have a complex structure and appear to be mylonitized. This implies strong differential movement and it must be acknowledged that fine dark shale several hundreds of feet thick would form a ready yield zone along which thick competent formations might slide when compressed by mountain-building forces. The exotic blocks of Arbuckle-type rocks that are distributed through the Johns Valley shale are thought to have been dragged from ridges in the southeastern prolongation of the Wichita and Red River mountains (consisting of Arbuckle-type rocks) that were overridden by the Ouachita thrusts. Harlton (*5*, p. 6) accepts this view. The scratches and slickensides on hard rock boulders and the locally contorted structure in shale, as seen in such exposures as that at Compton Cut, are generally accepted as due to folding, but this is regarded as an altogether local matter that is probably quite unrelated to conditions of forming the boulder-bearing shale.

Chief objections to tectonic hypotheses of the origin of the Johns Valley shale lie in the apparent lack of agreement between postulated and actual geologic structures in the Ouachita Mountains area and in the occurrence of the boulder-bearing shale at a constant stratigraphic horizon instead of various different horizons.

The comparatively gentle structure of the rocks in Johns Valley and the simple open folds of certain other parts of the Ouachita area where the boulder-bearing shale occurs, seem to preclude the possibility that the Johns Valley shale was formed by overthrusting of any conceivable sort. It seems very doubtful to me if any of the boulder-shale can be explained as derived by faulting from rocks beneath the Ouachita thrusts. This hypothesis of a "tectonic moraine" dragged along in a shale-lubricated shear plane is especially inharmonious with structural conditions observed in the Johns Valley area. No one has published any diagrams attempting to illustrate the derivation and transportation of the boulders by faulting. I have tried several times to construct such graphic representation of the conjectured tectonic origin of the boulders, but have been quite unable to formulate a remotely plausible picture according with observed structural and stratigraphic relations of the Johns Valley shale. Until this can be done, the tectonic hypothesis is not very convincing. The observed uniformity of stratigraphic position of the Johns Valley shale above Jackfork and beneath Atoka is very important, for when account is also taken of the considerable area of distribution of the Johns Valley shale, constancy of stratigraphic relations serves in itself virtually to deny the possibility of Van der Gracht's hypothesis. If the mechanics of the latter is accepted, it is hardly conceivable that other shales of the Ouachita Mountains sequence should not also contain boulders in some places, or that occurrence of "Johns Valley shale" at stratigraphic horizons other than between Jackfork and Atoka should not be found. We may, therefore, dismiss the suggestion of purely tectonic origin of the boulder-bearing shale because it is not accordant with observed structural and stratigraphic relations.

Hypothesis Here Proposed.

Source of the Boulders.—It is evident from study of the erratics in the Johns Valley shale that these were derived from rocks of Arbuckle or Ozark facies, the source of which can be assigned definitely to territory lying west, northwest, or north of the original geosynclinal area of Ouachita sedimentation. Deposits consisting largely of limestone, such as are now exposed in the Arbuckle and Ozark areas, form the normal Paleozoic geologic column of the interior continental platform or foreland area. With some variation, but no essential interruption, this type of column borders all of the western side of the Appalachian geosyncline and occurs along the interior border of the Ouachita-Marathon geosyncline to West Texas. A geosynclinal belt, in which clastic sedimentation was dominant, existed during Paleozoic time in the Appalachian, Ouachita, and Marathon districts, and it is probable that this was all a single continuous belt. Beyond the geosyncline to the east and southeast lay the extensive borderland (or hinterland) that supplied most of the geosynclinal sediments. This regional picture, supported by many geologic evidences, is now recognized, but with Miser and others I hold that the original site of the Ouachita geosyncline was by no means so far south as postulated by Van der Gracht (*15*, p. 999), that is, in the region of the present Gulf Coastal Plain south of the Sabine Uplift in Louisiana. In any case it is clear that the source of the Johns Valley boulders is some part of the rock succession that bordered the Ouachita geosyncline on the side toward the continental interior.

In the effort to locate the geographic source of the boulders more exactly, I agree with Miser, Powers, Van der Gracht and Tomlinson that the present Arbuckle area may be eliminated. The essential reasons for this conclusion rest on evidence that important folding in this area did not occur until much later (post-Hoxbar or post-Missouri) in Pennsylvanian time and on the absence of any boulder-bearing shale on the flanks of the Arbuckle Uplift. Folding or faulting with several thousands of feet vertical displacement was certainly necessary in the source area of the boulders in order to expose Early Paleozoic formations that are abundantly represented in the Johns Valley erratics. No movement of this sort in the Arbuckle area in post-Wapanucka pre-Atoka time is known. At the northeast margin of the Arbuckles, however, it has been shown that there was some pre-Atoka uplift, for the Atoka and McAlester formations overlap Wapanucka onto Caney and there is locally conglomerate containing limestone pebbles apparently derived from Viola and Arbuckle limestone (Morgan). It is possible, therefore, that an eastward extension of the Arbuckles, now concealed beneath part of the Coalgate Basin and the northwestward overriding front of the Ouachitas, may have supplied some of the Johns Valley erratics.

A source suggested by Van der Gracht (*17*) is the assumed southeastward extension of the Wichita-Criner Hills mountain uplift. This suggestion is supported by definite evidence that the Wichita chain was strongly uplifted in post-Morrow (post-Otterville, post-Bend) pre-Atoka (pre-Deese, pre-Strawn) time. Van der Gracht (*15*, p. 1010) has appropriately designated the crustal movements of this time in the central and southern Mid-Continent as the Wichita orogeny. The age of this deformation corresponds to that which must have given rise to the Johns Valley boulders (if they are a sedimentary deposit), and the type of rocks involved, probably including southeastward extensions under the overthrust front of the Oklahoma portion of the Ouachitas, is of the required sort. Opposing evidence, however, is found in the fact that the boulder-bearing beds are now known to extend well into Arkansas, and this fact, together with the westward and northwestward movement of the Ouachita rocks in subsequent folding and thrusting, requires either that the interior continental platform type of sediments along the Wichita axis must extend much farther southeastward under the Ouachita cover than seems reasonable, or that the boulder masses in Arkansas must have been transported an unbelievable distance eastward as well as northward from their supposed source. In this connection it must be recalled that the interior platform or foreland type of geologic section extended southeastward in the southern Oklahoma-northern Texas region only to the here south-trending border of the geosyncline, and rocks of the Arbuckle type cannot have extended southeastward along an extension of the Wichita-Criner axis farther than the border of this geosyncline. A further reason for rejecting Van der Gracht's hypothesis as to source region of the erratics is the very great horizontal thrusting of the geosynclinal sediments which is necessitated and which he believes has occurred. Miser (*9*, p. *27*) estimates that crustal shortening in the Arkansas part of the Ouachita Mountains, in which little thrust faulting is recognized, is about 50 miles and that the shortening in the Oklahoma part is perhaps 70 miles. Van der Gracht (*15*, p. 999), on the other hand, considers that the horizontal shortening was probably more than 200 miles.

The Ancestral Ouachita Mountains.—The suggestion may now be advanced that the required area of post-Morrow pre-Atoka uplift involving a foreland limestone section was located along that portion of the geosynclinal border most closely adjacent to the area of Johns Valley shale distribution. This signifies an area approximately parallel to the present northwest front of the Ouachita Mountains but somewhat south and southeast of the present front, for the post-Atoka Ouachita orogeny has involved an unknown amount of northward and northwestward thrusting of the geosynclinal sediments. The indicated site of this uplift, which I suggest may appropriately be termed the Ancestral Ouachita Mountains, essentially coincides with Powers' (*10*, p. 1044) "pre-Ouachita uplift." It seems to provide all of the necessary conditions as regards type of rocks involved and offers a source nearest to the areas where the boulders were deposited. It may be noted incidentally that the border zone between foreland and geosyncline is a belt of anticlinal tendencies that is likely to yield by upfolding or faulting to crustal stresses. Evidence from the erratic materials in the Johns Valley shale indicates that the postulated Ancestral Ouachita uplift occurred in post-Wapanucka time. Subsequently it may have been beveled by erosion and concealed by Atoka sedimentation, but in any case the site of the uplift has been overridden by the northwestward thrusts of the Ouachita orogeny in the Oklahoma structural salient. The occurrence in the Arkansas area of erratics that most closely resemble Ozark formations agrees with the inferred location of the Ancestral Ouachita uplift.

Deposition of the Boulders.—Assuming the validity of the inferences that have been made concerning the existence, general location and age of the Ancestral Ouachita Mountains, it is appropriate to consider how the Johns Valley shale was formed and how the boulders were transported from their postulated source in the Ancestral Ouachitas to their resting place in the shale. I favor the idea that as an accompaniment to the Ancestral Ouachita deformation, a part of the geosyncline south of the mountain front was depressed and submerged by moderately deep waters. This would seemingly provide conditions most suitable for deposition of fine dark muds. The indigenous fauna of the Johns Valley shale, comprised mainly of marine microfossils and essentially lacking bottom-dwelling larger invertebrates, agrees with this suggestion. We may preferably picture a steep mountain front, possibly a fault scarp, facing this sea, and we may imagine that large and small fragments of the uplifted rocks, loosened by weathering, by erosion of steep-dropping streams or of undercutting waves, or conceivably but improbably by work of ice, were dropped from the uplift into the bordering basin. Perhaps earthquake shocks incident to recurrent movements along a border fault zone helped to dislodge large rock masses. However separated from their mooring, when the "boulders" slid into the oozy mud of the basin it is probable that they found conditions very favorable for lateral creep. Bailey, Collet and Field (*1*, pp. 604-611) have called attention to examples of large exotic rock masses derived from fault cliffs, some of them probably by submarine landslips, and they note evidence of the extremely small gradient necessary to permit considerable lateral movement of the masses embedded in soft muds. We do not know from actual observation how far large boulders resting on or partly embedded in soft mud may be transported through agency of mud flow or creep, nor what minimum gradient is necessary. The fact that some of the rock masses in the Johns Valley shale would have to have been carried some 20 miles may be urged as opposing this hypothesis, but movement due to creep is deemed more plausible than transportation by floating ice.

The absence of thick conglomerates, so far as known, in the vicinity of the Ancestral Ouachita uplift is suggested as possible opposing evidence of existence of the uplift. Conditions did not favor the spreading of conglomerates in the area of Johns Valley sedimentation but this does not mean that conglomerates are lacking on other flanks of the uplift. Conglomerates occur in places at the base of the Atoka in southeastern Oklahoma and may be present in quantity in the concealed area of the deep Arkansas River trough.

Dixon (*3*, pp. 342-343; *4*, pp. 91, 92) notes striking similarity of limestone boulders in the mid-Carboniferous Bowland shale in north central England to the Johns Valley boulders of the Ouachita region and interprets the Bowland boulders as derived by landslips from scarps along active faults of the Cravens system. The geologic relationships are more clearly defined in the area studied by Dixon, for the location of the fault system and proof of mid-Carboniferous movements along it are known. In the Ouachita region, subsequent folding and faulting have concealed the assumed source region of the Johns Valley boulders. After formulating the conclusions as to origin and age of the Johns Valley deposits as presented here, and after completing part of the writing, it is interesting to discover that Dixon, whose knowledge of the Ouachita area is drawn entirely from the literature, offers explanation of Johns

Valley conditions and history that is practically identical with mine.

Markings on the Boulders.—The striations, gouges and other described markings on the Johns Valley boulders are apparently not satisfactorily explainable as the work of ice. They show distortion effects such as incipient cleavage and slickensiding that extend beneath the surface. There is appearance in some cases of plastic flow. All of these features may possibly be explained as effects of movement along the border faults of the Ancestral Ouachitas, which it has been suggested were formed by uplift totaling thousands of feet. If the scratches were made in the course of fault movements, there would have been nothing to obliterate them after they slid into the soft bed of accumulating Johns Valley muds. Some additional striation and slickensiding were almost certainly occasioned in places by the abrasion of one boulder on another during the Ouachita orogeny (Late Pennsylvanian or Permian).

AGE OF THE JOHNS VALLEY SHALE.

From the evidence that has been reviewed, we may conclude that the Johns Valley shale was deposited on the Jackfork sandstone and not carried there by faulting. Accordingly, the Johns Valley is younger than Jackfork sandstone. The occurrence of Atoka sandstone above the Johns Valley in every unbroken succession proves that the Johns Valley is older than Atoka.

The apparently conflicting evidence of the Caney fossils in the Johns Valley outcrop areas has been explained and we may now class all of the Caney fossils, both the loose reworked ones and those in the Caney shale masses, as erratic elements in the Johns Valley shale. This of course means that the Johns Valley is younger than Caney. Finally, the recognition of erratics of Morrow age shows that the Johns Valley formation is younger than at least part of the Morrow beds. Therefore, the Johns Valley is post-early Morrow and pre-Atoka. If the fossil-bearing rocks of Morrow age that occur in the Johns Valley shale are portions of beds deposited along with the shale, as believed by Miser, the Johns Valley formation is at least in part of Morrow age.

On the southwest flanks of the Ozarks the basal Atoka rests unconformably on Morrow beds. On the northeast flanks of the Arbuckles it likewise rests unconformably on Morrow (Wapanucka) and there is evidence of overlap. In the Ouachita Mountains outside the area of Johns Valley distribution the Atoka lies parallel, but very probably with disconformity, on Jackfork sandstone. Taking into account the known Late Mississippian or Early Pennsylvanian age of Jackfork and considering paleogeographic probabilities, the stratigraphic relations just noted suggest the possibility that the Jackfork sandstone is of Morrow age. The lower Morrow of northwestern Arkansas is notably sandy although also distinctly calcareous. It rests disconformably on Upper Mississippian dark shales, thin limestones and sandstones. The Jackfork is a thick sandstone which was deposited much nearer the source of sediments in lands to the south. It rests on thick dark shales and sandy beds that are apparently not older than Late Mississippian. Jackfork beneath Atoka is identified in Sebastian, Logan, and Yale counties, Arkansas, some 25 miles north of the Ouachita Mountain front and only a little more than 25 miles from the nearest outcrops of the Morrow beds overlain by Atoka in Crawford County farther north. The probable equivalence of Morrow and Jackfork is shown on sections published by Croneis (*2*).

In this connection the large fauna of Morrow species obtained by C. W. Honess (*6*) from a thick succession of sandstone which he called Jackfork, in the northwest corner of McCurtain County, Oklahoma, may be noted. The beds above the horizon containing this fauna have been subsequently classed as Atoka but it is possible that the fossiliferous horizon is really a bed in the upper Jackfork, corresponding, as was supposed by Honess, to the Wapanucka limestone of areas farther north.[4] The occurrence of this fauna may be regarded as supporting the inferred Morrow age of the Jackfork.

Mississippian-Pennsylvanian Boundary.—On the north and south flanks of the Arbuckle Mountains the Late Mississippian Caney shale is followed conformably or with apparently slight break by sandy beds called "Pennsylvanian Caney" or Springer, and this is conformably overlain, in turn, by limestone and shale containing a Morrow fauna. Following deposition of these beds, however, the important Wichita orogeny occurred, involving uplift of the Criner Hills and several other axes toward the west and south and there was at least some uplift of the northeastern Arbuckles. This uplift is marked in the Ardmore Basin by the Bostwick conglomerate in the middle of the Dornick Hills formation of Tomlinson (*13*), which I regard as more appropriately constituting the basal unit of the Deese. The Bostwick and succeeding Deese beds overlap on the pre-Carboniferous rocks of the Criner Hills. North of the Arbuckles, the Atoka and higher Pennsylvanian beds overlap on Caney and older rocks.

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[4] See Moore, R. C., The Mississippian-Pennsylvanian boundary in the Mid-Continent region: *Am. Assoc. Petroleum Geologists, Bull.*, to appear.

The uplift of the Ancestral Ouachita Mountains, as inferred from study of the Johns Valley shale, is a crustal movement that coincides in time with the movements noted in the Arbuckle area. Regional study of the unconformity at the base of the Atoka in the Mid-Continent region, and comparison with geologic relations in the Appalachian and other districts, lead me to conclude that much the most important break in sedimentation in this part of the geologic column is that at the base of the Atoka and equivalent beds. The Morrow deposits are paleontologically distinct from the Chester, but they resemble them lithologically much more than they do the overlying Pennsylvanian rocks, and they lie structurally conformable on Chester. The Morrow group has been classed as Pennsylvanian essentially because of the correlation of the flora above the Bloyd shale coal with a middle Pottsville (*18*, p. 316) flora in the central Appalachian district. The invertebrate marine fauna also contains a number of genera of Pennsylvanian type mingled with typical Mississippian forms (*7*). A Morrow marine invertebrate fauna occurs in the Parkwood formation of Alabama, which unconformably underlies the base of the Pottsville, just as the Morrow occurs unconformably below the similar Atoka formation. Clearly the Morrow cannot be equivalent to the Parkwood and at the same time equivalent in age to the mid-Pottsville.

After consideration of evidence much more extensive than can be presented here, I am led to conclude that the unconformity at the base of the Pottsville in the Appalachian region, at the base of the Atoka and Cherokee in most of the Mid-Continent area, at the base of the Deese formation (defined to include the Bostwick conglomerate at the base) in the Ardmore Basin, and the base of the Strawn in north central Texas may be considered as marking the base of the Pennsylvanian system. In the Ouachita Mountains area the Pennsylvanian-Mississippian boundary should be drawn at the base of the Johns Valley shale, or where that formation is absent at the base of the Atoka formation.[5]

SUMMARY.

The Johns Valley shale, with maximum thickness of 1,500-2,000 feet, occurs along the northwestern border of the Ouachita Mountains in west central Arkansas and southeastern Oklahoma. It lies with parallel structure on Jackfork sandstone below and is succeeded with apparent conformity of structure by the Atoka formation.

The Johns Valley shale contains many pebbles, cobbles and boulders, the latter up to a few hundred feet in diameter, all of which are derived from formations of the Arbuckle-Ozark type which are foreign to the geologic section of the Ouachita geosyncline. The erratic constituents range in age from Arbuckle (Cambro-Ordovician) to Morrow? (tentatively classed by me as latest Mississippian).[5] To be included among the erratics are large masses of Late Mississippian Caney shale. It is these masses that mainly have led to confusion in determining the age of the Johns Valley formation.

Evidence is presented to show that in post-Morrow time an important uplift of Ozark-Arbuckle type rocks occurred along the region now occupied by the northwestern front of the Ouachita Mountains. This uplift, termed the Ancestral Ouachita Mountains, is presumed to have supplied "erratic materials" to a marine area of dark mud sedimentation lying to the south. After removal from the mountain uplift through agency of wave cutting, stream erosion or other agencies, probably including chiefly landslips along faults, it is suggested that the boulders were distributed through action of flowage or creep in the soft mud of the gently sloping sea-bottom.

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[5] Study carried on since the completion of this paper leads to the conclusion that preponderance of evidence favors classification of the Morrow and equivalent beds as Pennsylvanian. At present this is certainly the more conservative judgment. If additional investigations that are planned corroborate the Pottsville age of the Morrow beds, significant evidence bearing on diastrophic criteria as a basis of inter-regional correlation will be supplied.

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ANORTHOCLASE CRYSTALS AS AN INDEX OF THE MIGRATION OF PENGUINS.*

DUNCAN STEWART, JR.

A number of species of penguins have been noted in the Antarctic regions the best known of which are the Adelie (*Pygoscelis adeliae*) and the Emperor (*Aptenodytes forsteri*). The Adelie breeds during the Antarctic summer in various rookeries along the coast of the Continent. A few of these rookeries in South Victoria Land are, namely: Cape Adare, Cape Bird, Cape Crozier, Cape Royds, the southern slopes of Cape Jones, the northern slopes of Coulman Island, Duke of York Island, Inexpressible Island, and the southern shores of Wood Bay. In contrast to the habits of *Pygoscelis adeliae* the Emperor penguin breeds on the sea ice during the dark days of July. The first Emperor rookery was discovered by Lieutenants Royds and Skelton, of the National Antarctic Expedition, 1901-04, on the sea ice beneath Cape Crozier, Ross Island, South Victoria Land. Another rookery was found on a flow about one mile from Haswell Island, Queen Mary Land, by the Australasian Antarctic Expedition, 1911-14. The Emperor penguin is now known to exist in Queen Mary, South Victoria, and King Edward VII Lands. It has been noted in the Antarctic Archipelago by the Swedish Antarctic Expedition, 1901-03, and as far north as the South Orkney Islands. They have been seen as far south as latitude 78° S. in South Victoria Land.

The food of the Emperor penguin consists mainly of small fish and cephalopods. The Adelie, in the region of South Victoria Land, feeds almost entirely on *Euphausia superba*—a shrimp-like crustacean.

Brief statements recording the presence of pebbles in penguins' stomachs are noted in a few expedition reports and in some narratives of Antarctic exploration. Wilson[1] remarks that pebbles were always present in the stomachs of both the young and old Emperor penguins, but Gould[2] states that not all of the birds have stomach pebbles, and considers their presence as quite accidental. The penguin does not possess a separate crop or gizzard. These pebbles are undoubtedly picked up at the bottom of shallow seas or on floating glacier ice.

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* Part of a dissertation submitted in partial fulfillment for the degree of Doctor of Philosophy, in the University of Michigan.

[1] Wilson, E. A., Aves: National Antarctic Expedition, 1901-04, Natural History, Vol. II, Zoology, Part II, p. 15, 1907.

[2] Gould, L. M., Cold, p. 57, New York, 1931.

Collections of pebbles were secured from the stomachs of Emperor penguins by Dr. Gould in the Bay of Whales area. Some 400 pieces, exhibiting a variety of rock types, sizes and shapes (Fig. 1), were examined under binoculars. The largest pebble measures 13 × 19 × 27 millimeters. The larger fragments make up approximately five per cent, medium 20 per cent, and small 75 per cent of the total number of pieces. Impure sandstone, granite, mica gneisses and schists, and anorthoclase crystal fragments each make up some five per cent of the total. Fig. 2 exhibits a few of the anorthoclase crystals. The other 80 per cent is composed of extrusive igneous rocks including hornblende trachyte, kenyte, basalt, amygdaloidal basalt, basalt scoriae, and other finely-crystalline gray, buff, green, red, brownish-black, and black extrusive types. Included with the pebbles are six lenses of fish eyes. The six lenses vary from pearly-white to yellow in color, and range from .507 millimeters to approximately 1.57 millimeters in diameter.

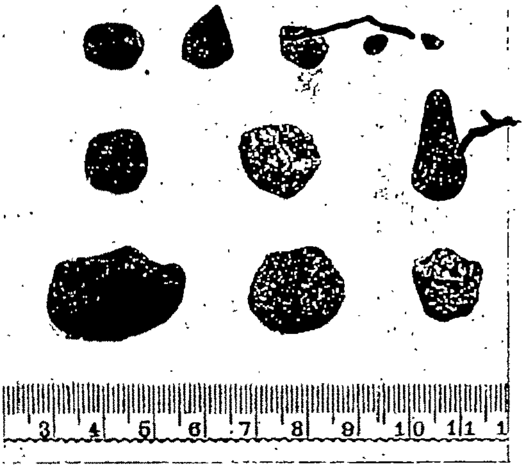

Fig. 1. Pebbles from an Emperor penguin's stomach.
(Scale in centimeters.)

The occurrence of kenyte containing phenocrysts of anorthoclase, is limited in South Victoria Land to the general area of the Ross Archipelago, and inasmuch as, some five per cent of the pebble contents of the penguins' stomachs collected by Gould is anorthoclase, it is suggested that the birds caught in the Bay of Whales had migrated some 350-400 miles from the vicinity of the Archipelago.

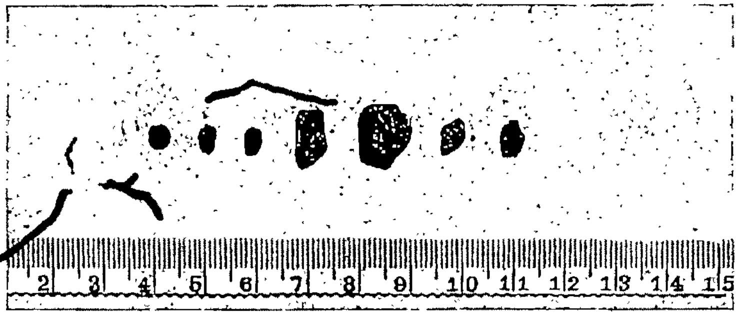

Fig. 2. Anorthoclase crystals from an Emperor penguin's stomach. (Scale in centimeters.)

RÉSUMÉ.

The Adelie and Emperor penguins have a wide distribution in the Antarctic regions. In a number of instances it has been recorded that pebbles have been found in the stomachs of these birds. Gould's collection of stomach pebbles taken from the Emperor penguin in the Bay of Whales exhibit a great variety of rock types. Five per cent of the total 400 fragments examined are anorthoclase crystals derived from the kenyte of the Ross Archipelago. It is suggested that the birds migrated some 350-400 miles to the Bay of Whales.

ACKNOWLEDGMENTS.

The author wishes to acknowledge the opportunity afforded by Dr. L. M. Gould to study the pebbles from the penguins' stomachs, and to thank Professor E. C. Case of the Museum of Paleontology of the University of Michigan for identifying the lenses of fish-eyes.

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PRELIMINARY NOTICE OF A NEW SPECIES OF *HIPPOHYUS* FROM INDIA.

SCIENTIFIC RESULTS OF THE YALE NORTH INDIA EXPEDITION. REPORTS ON VERTEBRATE PALEONTOLOGY.

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The species of *Hippohyus* described herewith is of exceptional interest, since it was collected by the author at a stratigraphic horizon lower than the oldest strata from which the genus has hitherto been recorded. Moreover, the primitive characters to be expected in such a specimen offer a better idea of the development of the genus and its relationships to the typical Suidae.

Description.

HIPPOHYUS DETERRAI[1], n. sp.

Holotype.—The incomplete skull, with the entire superior molar series and the last two superior premolars in perfect condition, and with the roots of the second superior premolars (Y. P. M. No. 13812).

Locality.—3¾ miles WSW of Hasnot village, near Dhok Potha, Dhala Nala, District Jhelum, Tahsil Jhelum, in the Punjab; Yale North India Expedition paleontological locality number 94; *Survey of India Map No.* 43 H/5, A-3.

Horizon.—Lower *Middle Siwalik*—*Nagri.*

Diagnosis.—The size is exceptionally small. The molars are relatively short and broad, with typical *Hippohyus* enamel folds. The measurements in the following table are diagnostic:

P^3	length	8	mm.
	width	7	mm.
P^4	length	8	mm.
	width	9	mm.
M^1	length	11	mm.
	width	11	mm.
M^2	length	12	mm.
	width	11.2	mm.
M^3	length	12	mm.
	width	10	mm.
Length from P^3 to M^3, inclusive		50	mm.
Length of molar series		35	mm.
Palatal width at P^3		19	mm.
Palatal width at M^1		18	mm.
Palatal width at M^3 (anterior)		16	mm.

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[1] Named in honor of Dr. Hellmut de Terra, leader of the Yale North India Expedition.

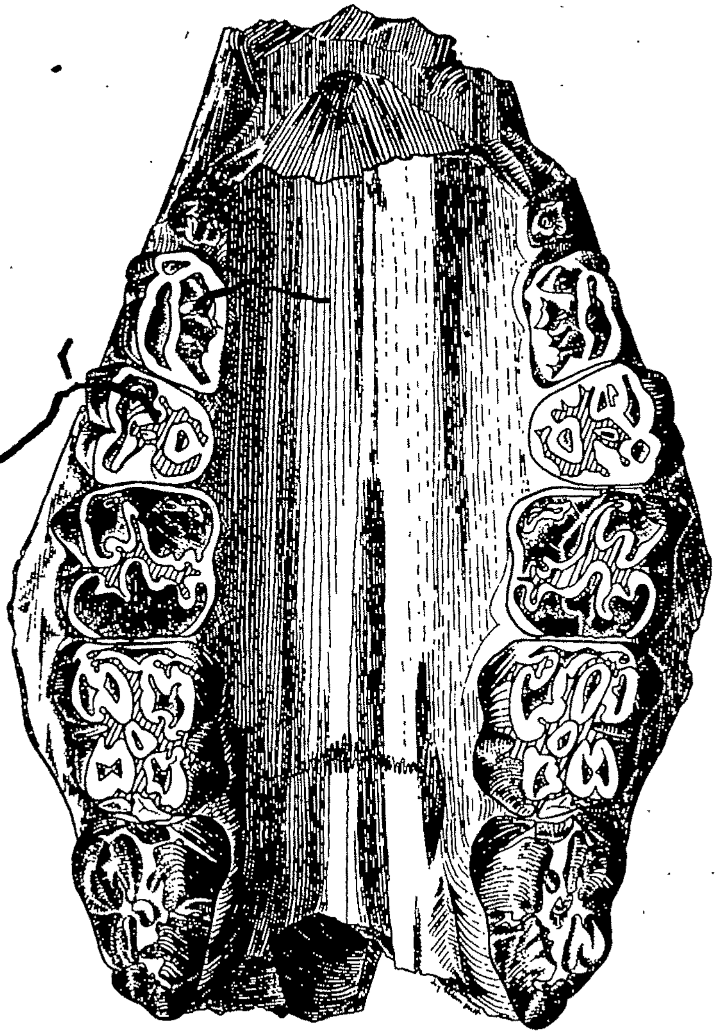

PLATE I. *Hippohyus deterrai*, n. sp. Holotype Y. P. M. No. 13812. Twice natural size.

Dr. Pilgrim[2] has distinguished four species of this genus, viz.: *H. grandis*, *H. lydekkeri*, *H. sivalensis* and *H. tatroti*. As compared to these previously described species, none of which is recorded from a horizon lower than *Dhok Pathan* (upper *Middle Siwalik*), *H. deterrai* is in every way more primitive, as one would expect. While Pilgrim[3] cites no measurements, reference to the plates of his memoir, and to the very complete measurements which Lydekker[4] has given for *H. sivalensis*, clearly illustrate the great discrepancy in size between the Yale specimen and the species of *Hippohyus* described hitherto, *H. deterrai* being only approximately half as large as the aforementioned species of later geologic age. The greatest contrast is to be observed in the cheek teeth: in the later and more specialized forms the premolars are only half again as large as in the case of *H. deterrai*, but M^3 in the more advanced types averages twice as wide and upwards of 2½ times as long as in *H. deterrai*! Evolution in the genus *Hippohyus* was marked by lengthening of the skull and an increase in the size of the cheek teeth, with the molars becoming progressively more elongate and specialized from M^1 to M^3. The small size of the Yale specimen was not an age character, since maturity is indicated by the stage of wear of the dentition.

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[2] Pilgrim, G. E., 1926. "The Fossil Suidae of India," Mem. Geol. Surv. India, Pal. Ind., N. S., VIII, 4, pp. 50-52.

[3] Ibid.; pl. XVI, figs. 1-5; pl. XVII, figs. 1-3; pl. XVIII, fig. 6.

[4] Lydekker, R., 1884. "Indian Tertiary and Post-Tertiary Vertebrata," Pal. Ind., Ser. 10, III, 2, p. 86.

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THE AGE OF THE RENSSELAER GRAYWACKE.

HENRY VAUGHAN AND T. YATES WILSON.

The Rensselaer Plateau is a prominent physiographic feature which comprises nearly one-third of Rensselaer County, New York. It forms the surface of an elongated upland which has an east-west axis of nine miles and a north-south axis of twenty-three miles. The average elevation of the plateau is 1700 feet above sea level and 900 feet above the surrounding lowlands. The age and stratigraphic relations of the graywacke, named the Rensselaer Grit by T. N. Dale (1893, p. 291), which underlies the plateau have been subjects of controversy for many years.

Descriptions recognizing the Rensselaer plateau as a topographic unit seem to have been begun by Horatio G. Spafford (1813, p. 96), who wrote of "tracts of wet uplands covered with a luxuriant growth." Chester Dewey (1820, p. 246), writing in this Journal dealt with the Rensselaer graywacke and made a very careful study of this rock. Amos Eaton (1822, p. 20), described the graywacke and added "wherever the graywacke rests immediately on the argillite, it is the slaty variety, and takes on the form and position of the argillite." William Mather (1843, p. 368), published his final report on the region and correlated the Rensselaer grit with the Shawangunk grit; he believed there was no evidence for the unconformable relations which Eaton and Dewey had inferred to exist between the grit and its associated formations. From 1843 to 1887 the problem of the Rensselaer graywacke seems to have been somewhat submerged in the broader field of Taconic investigation, carried on at first by Ebenezer Emmons (1844, p. 1, et seq.), and later by James D. Dana (1888, p. 410).

Charles D. Walcott (1888, pp. 229, 395), correlated the Rensselaer grit with the Lower Cambrian (Georgian) presumably because of the lack of recognizable fossils. "The Rensselaer Grit Plateau in New York," by T. Nelson Dale (1893, pp. 291-340), was published in the Thirteenth Annual Report of the United States Geological Survey. This was a very thorough discussion of the petrographic character of the grit. Because of lithologic similarities and seeming stratigraphic unconformities Dale correlated the Rensselaer with the Medina (Silurian) conglomerate. R. W. Ells (1895, p. 9), took exception to this, reiterating Logan's former claim of a Levis (Ordovician) age for the grit. Dale (1904, p. 50), later continued to adhere to his original views. C. A. Hartnagel (1907, p. 51), expressed his belief that the Rensselaer grit must be Upper Silurian or Devonian. John M. Clarke (1909, p. 159), published the conclusicns of Rudolf Ruedemann that the grit was of Upper Devonian age. Ruedemann reached his decision after comparing the structure and lithology of the Catskill beds with that of the Rensselaer grit as exposed in a small outlier in Austerlitz, about fifteen miles south of the main body of the grit.

After a long and careful study of the Taconic region, Prindle and Knopf (1932, p. 248), tentatively assigned the Rensselaer graywacke to the Lower Cambrian. This assignment was made because of the fact that beds of the graywacke were found to dip in apparent conformity under the Rowe schist of Taconic Mountain "and also because there is interbedded with the graywacke a large amount of slate similar to slate of known Lower Cambrian age."[1]

The writers of the present paper have been carrying on an investigation and field study of the Rensselaer graywacke in general and especially that part of it composing the Brainard "outlier." This paper gives notice of recently found evidence which seems to aid in establishing the age of this formation.

The Brainard occurrence, as mapped by Dale, is about seven miles long, reaches a maximum width of about one mile and extends from East Nassau, New York, in a south-southwesterly direction to a point about a mile south of Old Chatham. This occurrence is not shown on the latest map of the United States Geological Survey; Mr. Prindle, however, advises us that it should be indicated.

Specimens of the graywacke and the associated shales from the Brainard graywacke area closely resemble other specimens taken from various localities within the main body of the Rensselaer Plateau; the regional strike and dip of the rocks also are the same. The Brainard area also contains the typical associations of red and green shales with massive graywacke which characterize the main plateau.

At three localities within the Brainard graywacke area the writers have discovered *Oldhamia* (*Murchisonites*) cf. *occidens*. The first occurrence is in the gorge below the falls of an unnamed stream in the village of Old Chatham. The second locality is about a mile farther up the same stream where it is crossed by a railroad and highway. The third locality is in a railroad cut by the grade crossing about one mile southwest of Brainard station. In all three occurrences the *Oldhamia* are found on the surfaces of thin, red arenaceous shales, and at the third locality are found on surfaces of green shales as well. In all cases the *Oldhamia*-bearing beds are interbedded with massive graywacke.

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[1] Knopf, E. B., Personal communication.

The genus *Oldhamia* (*Murchisonites*) is generally believed to be a reliable guide for the Lower Cambrian. It was first described from Ireland by Edward Forbes (1848).[2] Later it was described from the United States and New Brunswick by C. D. Walcott (p. 314, 1894); G. F. Matthew (1900); T. N. Dale (p. 13, 1904); B. F. Howell (p. 198, 1922); E. S. C. Smith (p. 484, 1928), and R. Ruedemann (p. 47, 1929). It is of interest to note the report of Walcott's first *Oldhamia* localities, all in Rensselaer County. The descriptions were supplied by Dale, who said:

> "The *Oldhamia* was first found in reddish shales associated with greenish shales and beds of quartzite ranging from 1 to nearly 22 inches in thickness . . . ."

Oldhamia have subsequently been found in a similar association of reddish shales, greenish shales and quartzites. Often the shales approach true slates.

Because of the similarity between the massive graywacke beds of the main Rensselaer Plateau and those associated with the shales (in which the writers have found the *Oldhamia*), Dale concluded that the rocks of the Brainard "outlier" were the same as those in the main body.

It appears, therefore, that the finding at three scattered localities of beds carrying *Oldhamia* which appear to be in structural unity with the graywacke, together with the lithologic character and stratigraphic position of the Brainard rocks, suggests that the Rensselaer graywacke is of Lower Cambrian age. The conclusion of Walcott on lithologic grounds in 1888, and the tentative conclusion of Prindle and Knopf in 1932 are strengthened by the paleontological evidence presented here for the first time.

The writers wish to thank Dr. E. B. Knopf and Prof. E. S. C. Smith for helpful criticism of the manuscript of this paper.

[2] Jour. Geol. Soc. Dublin; Vol. 7.

UNION COLLEGE,
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DISCUSSIONS AND COMMUNICATIONS.

THE UPPER JURASSIC AGE OF THE TENDAGURU DINOSAUR BEDS.

The Tendaguru series of East Africa is interesting to Americans chiefly because its late Jurassic dinosaur horizons, with forms very much like those of our Morrison formation, are interbedded with marine strata replete with bivalves and eight species of ammonites. The work of the Germans up to 1918 was reviewed by the writer in his "Age of the American Morrison and East African Tendaguru Formations," published in the *Bulletin* of the Geological Society of America, vol. 29, 1918, pp. 245-280. A later paper on "The Age of the Morrison Formation," by G. G. Simpson, also reviewed the faunal and stratigraphic evidence of this formation (this Journal, 12, 1926, pp. 198-216). After the Great War, the English continued the investigation of the Tendaguru series and made further collections of dinosaurs, and Parkinson presented the newer results in his interesting book, "The Dinosaur in East Africa," 1930, following this by a "Note on the Geology of the Country around Tendaguru, Lindi District" (Geol. Surv. Dept. Tanganyika Terr., Short Paper No. 6, 1930). The correlations of the Germans and others were questioned in a critical paper by F. L. Kitchin entitled "On the Age of the Upper and Middle Dinosaur-Deposits at Tendaguru, Tanganyika Territory" (Geol. Mag., vol. 66, 1929, pp. 193-220); on the basis of the bivalves chiefly, he concluded that all of the Tendaguru series above the Nerinea division is of Neocomian or Valanginian age, and that even the Nerinea beds may be of the same general time. The decisive evidence of the ammonites he discounted, saying that "the Jurassic ammonites found in the '*Trigonia smeei*' sandstones are not in their original position, but were derived into those beds, the true age of which must be determined by their latest fossils" (p. 218).

This criticism by Kitchin stimulated Dietrich to restudy most carefully and in great detail all the invertebrate faunas, of which the collections are indeed very large, and the results of this investigation he now gives us in a memoir entitled "Zur Stratigraphie und Palaeontologie der Tendaguruschichten" (Palaeontog., Suppl. VII, 2. Reihe, II, 1933). He was most careful to ascertain whether or not the ammonites show any evidence of having been introduced from older beds, and found no such indications, but admits that they have been drifted from deeper water into these littoral deposits. The marine fauna of the basal Nerinea division, with its many bivalves, had not been carefully studied with a view to age determination, and this Dietrich has now done. The succession of the various divisions, and their former and present correlations, are given in the following table:

Correlations of the Tendaguru Series of East Africa.
(After Dietrich 1933)

Time	Divisions by Dietrich		Original divisions	Kitchin's correlations
Aptian	Urgonian		Makonda calcareous beds	
Lower Aptian to Hauterivian and upper Valendian	Schwartzi division	Ss. with *T. bornhardti*	*Trigonia schwartzi* ss.	Neocomian
		Ss. with *T. schwartzi*		
	Marked disconformity			Break
Lower Portlandian to Kimmeridgian and Sequanian ?	Smeei division	Upper Dinosaur beds	Upper Dinosaur sandy clays	Neocomian or Valanginian (Valendian)
		Littoral beds with *Cyrena-Mytilus*	*T. smeei* ss.	
		Ss. with *T. smeei*		
		Littoral beds with *Cyrena-Mytilus*		
		Middle Dinosaur beds	Middle Dinosaur sandy clays	
		Littoral beds with *Cyrena-Mytilus*	Nerinea ss.	? Infra-Valanginian
		Ss. with *T. dietrichi*		
			Lower Dinosaur sandy clays	?
			Great break	
			Gneiss	

Parkinson regards the Jurassic succession up to the *Trigonia schwartzi* division as a near-shore series of continuous deposits of a sinking shelf-sea, with the dinosaur divisions as local developments resulting from river delta extensions outward into the sea. The Germans, on the other hand, look upon these alternations of marine littoral and neritic deposits as laid down in an area oscillating between land and sea conditions. The sea bottom and the land were nearly flat, and the streams, flowing easterly through low hills of gneissic rocks, finally meandered through coastal lagoons into the littoral sea. The total thickness of deposits in the Tendaguru series is over 400 feet. There were no coastal cliffs or highlands from which Jurassic boulders with ammonites could have come, and all of the rare conglomeratic material, with the exception of an occasional gneiss pebble, is of intraformational origin. Dinosaur bones were occasionally washed out, but none of these is rolled and worn, and some of them are overgrown with oysters. The transition from the Lower and Middle Dinosaur beds through the brackish beds to the wholly marine divisions with bivalves, gastropods, rare ammonites, serpulids, echinid spines, corals, crinoids, crustaceans, etc., is gentle, and even the Middle Dinosaur zone passes into marine beds to the north.

In the marine divisions, the bivalves are by far the most common types of animals, and they belong chiefly to the genus *Trigonia*. The shell banks are not constant in their vertical distribution, but shift and change with the changing depth and environment of the bottoms; in places, entire beds are replete with local accumulations of large shells, scattered among which are small bivalves, while ammonites, belemnites, and gastropods are rare. In places, there are local growths of corals.

Dietrich discusses and describes 8 forms of ammonites in 7 genera (3 specifically named), a single nautilid, 2 species of *Belemnopsis*, *Nerinella credneri*, and a *Pseudomelania*; the small patellids, he says, must remain unworked. Of bivalves, there are 90 species or varieties, in the main sand-loving forms; 54 are specifically named, and 17 are new. The new genera are *Indotrigonia*, *Transitrigonia*, *Tendagurium*, and *Epihippopodium*. Most of the bivalves help little to fix the age of the strata, and yet many of the guide fossils of the Schwartzi zone do not occur in the older Jurassic zones, and many of the older ones do not pass up into the Neocomian division. The bivalves do, however, indicate a great time break between the Jurassic and the Cretaceous.

Ammonites are rare in the Jurassic beds and in addition are not well preserved; they are found more often, and in better preservation, in the Neocomian divisions. Locally, small nests of them do occur, along with belemnites, even in the dinosaur zones. Although ammonites are rare and poorly preserved in the Nerinea division, none are of Neocomian or Infravalendian forms. Still more definite, no Portlandian or upper Tithonian forms are present. In the Smeei zone, all are Kimmeridgian perisphinctids, of forms that Spath has named *Katroliceras*, *Torquatisphinctes*, and *Subdichotomoceras*. Finally, the older zones have nothing indicative of Oxfordian time.

According to Dietrich, while one can argue for an Oxfordian age for the Nerinea division on the basis of bivalves and gastropods, the ammonites nevertheless indicate Kimmeridgian time only. All of the marine Jurassic with its intercalated dinosaur zones up to the Schwartzi division is one unbroken sedimentary and faunal series, and as the Middle Dinosaur division passes north into marine beds, therefore the Nerinea, Middle Dinosaur, and Smeei zones are surely of one continuous series correlating with the Kimmeridgian and lower Portlandian. No upper Portlandian guide fossil has yet been found in the Upper Dinosaur division.

A great paleontological break is indicated between the Schwartzi zone and the Upper Dinosaur beds. The absence of the Purbeckian and the marine Infravalendian indicates a break from upper Portlandian time until at least middle Valendian, since the sea appears to have come back again in upper Valendian or Hauterivian time.

In the Schwartzi zone, nearly all of the fossils are indicative of Cretaceous time, this being true of the ammonites, belemnites, numerous bivalves, some gastropods, and corals. Even the bivalves alone indicate the time to be middle Neocomian.

Dietrich concludes that the bivalves of the Tendaguru series indicate a separation of the series into two parts, namely, an Upper Jurassic Smeei division, and a Neocomian Schwartzi one. At present, however, it is not possible to zone either of these divisions, since the Tendaguru series consists of littoral-neritic sand deposits, and the necessary deep-water calcareous sediments and faunas are absent.

On paleontological grounds, Dietrich agrees with Parkinson that the Nerinea horizon and the two higher Dinosaur divisions are but local phases of Smeei time. As the Upper Dinosaur sandy clays are decidedly thicker than the Middle ones (130 feet against 50), it may be said that the Smeei horizon becomes increasingly brackish upward until the succeeding strata (Upper Dinosaur) are wholly of continental nature. Dietrich's paleontological work therefore confirms Parkinson's postulate of a marked disconformity at the top of the Upper Dinosaur beds.

The Mesozoic faunas of the entire East African Tendaguru series are of an independent marine province, which during the Upper Jurassic had indigenous, Indian, European, and cosmopolitan elements, and in Neocomian time indigenous, European, southern Andean, and cosmopolitan ones. From the widely spread mediterranean Tethys a broad seaway extended through Somaliland and central Arabia. With the Jurassic of India the connections are closer than with the South African Neocomian province. The East African *Trigonia* faunas also shed light on the long known and famous, but at first incompletely understood, bivalve faunas of the Jurassic of Cutch. CHARLES SCHUCHERT.

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SCIENTIFIC INTELLIGENCE.

PHYSICS.

Eléments d'Optique Géométrique; by PIERRE COPEL. Pp. 206; 127 figs. Paris, 1933 (Gauthier-Villars, 25 fr.).—This volume, devoted to the special field of geometrical optics, is designed for candidates to *Grandes Ecoles*. It is a sound, concise and logical development of the subject covering the usual topics except that a minimum of space is devoted to optical instruments. The book has several novel and interesting features of presentation, among them being the use of a "vector ray"—a vector having the direction and sense of the light ray and a magnitude equal to the refractive index of the medium. A. T. W.

Mass Spectra and Isotopes; by F. W. ASTON. Pp. xii, 248; 8 pls., 43 figs., 10 tables. London, 1933 (Edward Arnold and Co., also Longman's Green and Co., New York, $4.80).—This is a completely revised edition of the author's earlier book, *Isotopes*, the last edition of which appeared in 1925. It has been considerably altered in bringing the subject matter up to date, and the great progress in this field has necessitated narrowing the scope of the text. It is now primarily a source book for experimental methods and data in connection with the important subject of isotopy, or the study of the different varieties of atoms of any given element and their exact masses.

Part I deals with the historical development of the subject and describes the early experiments and their results. Part II discusses the technique of gaseous discharge and gives an account, valuable to the specialist, of the present methods of precision in measuring the masses of individual atoms and the relative abundance of different isotopes. Part III sets forth in a systematic manner the known facts bearing on the constitution of nuclei, as evidenced by the study of isotopes. As stated by the author, this part forms the groundwork of a new subject, which might be called "Nuclear Chemistry." The elements are dealt with according to the groups in the periodic table. The balance of the book, comprising Part IV, takes up topics of theoretical and general interest, and contains chapters on the electrical theory of matter, the statistics of isotopes, detection of isotopes in molecular and atomic spectra, and the separation of isotopes. The book is written clearly and in an interesting manner in spite of the necessarily large amount of numerical data, and will be welcomed by all who have an interest in atomic physics. A. T. W.

The Logic of Science; by WILLIAM G. BALLANTINE. 225 pp. New York, 1933 (Thomas Y. Crowell Co.).—The avowed purpose of this book is to give the average reader an exposition of the fundamental principles of scientific reasoning. Most of the text is given over to a discussion of logic with illustrations from science, and especially to a discourse on cause and effect. This is done in a rambling manner, with occasional unnecessary repetitions. The book is a mixture of the obvious, the confused and the shrewd, with a minimum of the last. The language is simple, the manner didactic. The author shows little insight in philosophy, and no real knowledge of science. His motives are praiseworthy and quite sincere, and some of his main points are well taken. A. T. W.

Physik für Jedermann; by A. HAAS. Pp. x, 274; 76 figs. Berlin, 1933 (Julius Springer, 6.80 RM. bound).—Lay readers in science owe a debt of gratitude to Professor Haas for his long list of writings on present-day physics, of which this volume is the latest. His writing is clear, interesting and authentic, and in these respects this book is no exception. It provides a survey of the main facts in physics which have led to modern research and invention. In addition to an account of the latest contributions to pure physics, a new and valuable feature of the present book is the description of modern technical application of physics. Thus, the section on *Light* includes a description of optical instruments and of photography (still and motion); under *Electricity* explanation is given of ordinary electrical machinery, of power transmission, telegraphy, telephony, radio, broadcasting, sound pictures and television; under *Heat*, steam engines and turbines, combustion engines, and refrigerating machines. The last fourth of the book is devoted to a discussion of *Matter*, in which is presented a summary of recent physical research, including the present startling developments in artificial transmutation of elements and the discovery of the neutron and the positive electron. A. T. W.

GEOLOGY AND MINERALOGY.

A Revision of the Ceratopsia or Horned Dinosaurs; by RICHARD SWANN LULL, Peabody Museum of Natural History, Mem. III, Pt. 3. Pp. 175, 42 text figs., 17 pls. New Haven, 1933.—In this stately volume Professor Lull returns to one of his first loves. It was twenty-seven years ago that he completed the first monograph on the Ceratopsia, a work that was begun by Hatcher and Marsh. Since then have come the discoveries of the bizarre types of the Red Deer Valley of Alberta, of skeletons associated with nests of eggs in Mongolia, and of many fine specimens of species which were represented only by fragments in 1907. The number of genera has increased to thirteen and the species to thirty-seven.

The present volume, which presents a systematic description of every known ceratopsian, includes also a general account of the morphology of the animal and a discussion of the habitat, habits and evolutionary history of the group.

The Ceratopsia were confined, so far as known, to the Cretaceous period and, with the single exception of the mongolian species, *Protoceratops andrewsi*, none have been found outside North America. They were most plentiful during the closing stages of the Cretaceous period on the low coastal lands that fringed the western and northern margins of the Rocky Mountain Seaway, and their remains are found chiefly in Alberta, Montana, Wyoming and Colorado.

Although the adults frequented this coastal lowland it appears that they retired to some other environment to lay their eggs and bring up their young, since juvenile specimens are exceedingly rare. Indeed, immature specimens have been found at only one locality in America and another in Mongolia. In the latter all stages of growth, as well as nests of unhatched eggs, are found.

That the Ceratopsia were pugnacious beasts is shown by the common occurrence of punctured bones and broken horns that had healed before death.

Plate I shows a striking restoration of a horned dinosaur which the author has modeled over a mounted skeleton of *Monoclonius flexus*. The splendid collotype plates of the volume are a fitting counterpart to the graceful style in which the facts are told.

C. O. D.

Geology of Coral Reefs; by PH. H. KUENEN. Pp. 125, 11 pls., 106 figs. Geological Results of the Snellius Expedition, Vol. 5, Part 2. (Utrecht, 1933.)—As geologist of an expedition in the eastern part of the Dutch East Indies in 1929-1930, Dr. Kuenen spent six weeks in a study of coral-reef phenomena. In this volume he presents the detailed results of his observations, which tend to confirm a growing opinion among students of coral reefs that these features have a more complex origin and history than has been maintained by some authors.

Dr. Kuenen favors the subsidence theory for the origin of most of the atolls he examined, although he shows that raised reef-terraces afford good evidence of uplifts,[1] and believes that W. M. Davis underrated this evidence. He gives a number of reasons for believing that Pleistocene eustatic lowering of sea level was not the chief cause of the formation of atolls, but holds that low glacial sea-levels were largely responsible for the uniformity of depth and flatness of bottom of the reef-encircled lagoons, by permitting low-level abrasion of the shallower lagoons and aggradation of the deeper lagoons.

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[1] Also pointed out by Hoffmeister; see review in this Journal, 25, p. 87, 1933.

Data on the several islands visited are given in detail, and the careful reasoning based on them lends weight to the conclusions. If there were available detailed studies of all the reefed islands of the Pacific, similar to those here presented by Dr. Kuenen, there would be far less room for differences of opinion among investigators. It might even be agreed by all of them that coral reefs have more than one mode of origin. RICHARD FOSTER FLINT.

Metalliferous Deposits of Greater Helena Mining Region, Montana; by J. T. PARDEE and F. C. SCHRADER. U. S. Geol. Survey, Bull. 842. Pp. 318, 47 pls., 36 figs. Washington, 1933.—The publication of a new report on a well-known region is always an event of great interest. In the Helena region the main geologic feature is the Boulder batholith, and the outstanding feature of the present report is that it gives a geologic map of 3000 square miles area that shows for the first time the geologic setting of the Boulder batholith. The conclusion is affirmed that the batholith was intruded in late Cretaceous or early Eocene time, under a rock cover probably 10,000 feet thick. Following earlier usage the authors term the granitic rock of the batholith a quartz-monzonite, but in reality it is a granodiorite, whether we follow the definition of Lindgren, of Iddings, or of Niggli, for the dominant feldspar is andesine (An_{40}) and it is present in amount double that of the orthoclase.

Two groups of ore deposits are recognized: An earlier, which is genetically related to the Boulder batholith; and a later, which is in part related to granodiorite stocks that may be Oligocene and is in part later than the extrusive dacite of Miocene age. In the case of the ore deposits at Marysville the authors have effected an ingenious reconciliation of older conflicting views. Barrell maintained that the ore deposits are genetically related to the Marysville granodiorite stock and belong in the same group as those associated with the Boulder batholith, because the stock was regarded as an outlier of the Boulder batholith. Because of their marked unlikeness to the older group and their complete resemblance to the younger group, Knopf thought that the ore deposits belong to the younger group and are not genetically related to the Marysville stock. Pardee and Schrader harmonize these views by regarding the veins as belonging to the younger group of ore deposits and as genetically related to the Marysville stock, but the stock is thought to be not an outlier (cupola) of the Boulder batholith but a much younger intrusion, probably of Oligocene age. This conclusion fits in with the belief that the Marysville stock was intruded at shallow depth, instead of "under the whole thickness of sediments—

namely, 10,000 feet or more," which were removed from the area during Eocene and part of Oligocene time.

The main part of the report, as implied by the title, deals with the metalliferous deposits, and the conclusion is reached that a long-continued mining activity on a moderate scale can reasonably be anticipated. ADOLPH KNOPF.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Catalogue of the British Museum of Natural History.—The second volume of the Supplement to the Museum Catalogue (seventh of the series) has recently been published, November, 1933. This is a quarto volume of 454 pages, extending from J to O. Its completeness is shown by the fact that the works of Carl Linnaeus cover 90 quarto pages, two columns each.

A Manual of Thesis-Writing for Graduates and Undergraduates; by ARTHUR H. COLE and KARL W. BIGELOW. Pp. ix, 48. New York, 1934 (John Wiley & Sons, 75 cents).—The many students who are called upon to write theses will find in this Manual much valuable information. This extends from the choice of subject, collection of data, composition, to the style and editing; even such points as the proof readers' marks are not omitted.

Reality and Illusion: A New Framework of Values; by RICHARD ROTHSCHILD. Pp. 442. New York, 1934 (Harcourt, Brace and Co., $3.50).—As stated by the publishers the aim of this book "is to formulate the background against which all current questions must be viewed. Attempting to express those vague feelings and aspirations of the common man which he himself may not understand or be able to clarify, it presents an analysis of how the new forces must work themselves out in science, morals, religion, art."

NOTE.

A New Stratigraphic Name.

In a paper by George H. Chadwick accepted for publication in this Journal, the new name "Conneaut group"* is employed to embrace the Upper Devonian Girard and Chadakoin shales of northwest Pennsylvania, or lower Chagrin of Ohio.

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* Caster, Kenneth E., Bulletins of American Paleontology No. 71, now issuing.

OBITUARY.

DR. WILLIAM HENRY WELCH, the distinguished pathologist of Johns Hopkins University and Hospital, died on April 30 at the age of eighty-four. His eminence in medical science and his contributions to it were universally recognized the world over.

DR. GEORGE CARY COMSTOCK, professor of astronomy at the University of Wisconsin and director of the Washburn Observatory until his retirement in 1922, died on May 11 at the age of seventy-nine.

DR. CLEVELAND ABBE, JR., geographer and meteorologist, died on April 16 at the age of sixty-two.

DR. CHARLES WRIGHT DODGE, professor of biology at the University of Rochester, died on April 17 at the age of seventy-one.

DR. CHARLES WESLEY ROLFE, professor of geology at the University of Illinois from 1885 till 1917, died on April 6 in his eighty-fourth year.

DR. CAMILLE MATIGNON, professor of physics and chemistry in the Collège de France and president of the Société Chimique de France, died on March 18 at the age of sixty-six.

DR. SYDNEY HOWARD VINES, from 1888 to 1919 professor of botany at the University of Oxford, died on April 5 at the age of eighty-four.

MR. E. G. B. MEADE-WALDO, the distinguished English ornithologist, died on February 28 at the age of seventy-nine.

DR. DAVIDSON BLACK, director of the Cenozoic Laboratory in Peking, died in March at the age of forty-nine.

PUBLICATIONS RECENTLY RECEIVED

Actualités Scientifiques et Industrielles. 81. I. L'Effet Volta par Emmanuel Dubois. 82. II. The Electrical Properties by M. A. H. Wilson. 83. III. On Phase Boundary Potentials by Eric Keightley Rideal. 84. IV. Pile Metalliche par O. Scarpa. 85. V. Das Elektrolytische Kristallwachstrum von M. Volmer. 86. VI. Les Electrons dans les Métaux par F. Bloch. 87. VII. Conductibilité Electriques des Isolants solides et des Semi-Conducteurs par A. F. Joffé. 88. VIII. Electrons dans les Métaux par Léon Brillouin.

Insects as Material for Study; by G. D. H. Carpenter. New York, 1934. (Oxford University Press, $1.00.)

Handbook of Technical Instruction for Wireless Telegraphists by H. M. Dowsett. Fifth Edition, revised. London. 1934. (Iliffe & Sons, 15/-net.)

Journal of the Iron and Steel Institute. No. 2. 1933. Edited by K. Headlam-Morley, Secretary. London, 1933.

The Mysteries of the Atom by H. A. Wilson. New York, 1934. (D. Van Nostrand Co., $2.50.)

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